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The Leeway of Persons-In-Water and Three Small Craft

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JULY 1999

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16. Abstract (MAXIMUM 200 WORDS)

Leeway behavior, the effect of wind on floating objects, of a variety of small survivor objects and situations is required to provide reliable inputs into Coast Guard search planning models. This series of leeway experiments extends a series of leeway experiments employing GPS navigation, miniature electromagnetic or acoustic current meters, and on-board weather stations. The experiments directly measured the leeway of small objects that may be involved in Search and Rescue activities by attaching current meters to the leeway objects. Collecting meteorological data continuously at or near the drift object improved the relationship of these data to the particular leeway object. Internal recording of measurements of wind and current, along with satellite positioning and telemetry, permitted greater data recovery and the ability to gather data during severe weather. A method to measure leeway of extremely small objects was developed making use, for the first time, of new current meter designs. Leeway values as a function of wind velocity were developed for a Person-In-Water (PIW) (wearing a personal flotation device or survival suit), Wharf Box, Sea Kayak, and Windsurfer. The leeway values are presented in three forms for search planners using the manual method, CASP (Computer Assisted Search Planning) program, and an advanced version of a leeway model that will replace the current CASP. This report concludes that the methods and instrumentation developed to measure the leeway of small survivor objects such as PIWs are accurate. Leeway values developed for the PIWs and the three small craft furnish the search planner, for the first time, with verifiable leeway planning guidance.

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EXECUTIVE SUMMARY

INTRODUCTION

When the Coast Guard prepares to conduct a search, search planners need to define an area over which the search will be conducted. The search planner's goal is to define the smallest search area that contains the survivors or survivor craft with a reasonable and predictable level of certainty. The search planner needs information about the Last Known Position (LKP) of the search object, the time of that LKP, the ocean currents and winds in the area of the search object, and the type of the search object. The size of the search area is directly related to the certainty to which these data are known.

The movement of survivors or survivor craft through the water, caused by wind acting on their exposed surface, is termed leeway. Both ocean currents and the leeway will displace the survivor or survivor craft from its LKP. While current-induced search object motion generally follows the surface water movement, the action of wind on a survivor or survivor craft leads to a drift direction that is usually different from the downwind direction. Since the only vector directions that search planners have at their disposal are those for wind and current, the direction of the leeway drift vector must be computed based upon individual leeway object characteristics. This report provides leeway vector data for four common search objects.

The concern for the effect of wind on survivor craft during World War II SAR operations dates to a study conducted by Pingree (1944). Since that original study, attempts have been made to improve and refine leeway search guidance and to expand the variety of SAR objects that have leeway drift information available. In the early 1990's, technology dramatically changed our capabilities to measure leeway directly. Satellite-based navigation and communications enabled objects and instruments to be tracked with precision and for their data to be recovered even in cases of equipment loss. Small self-contained current meters, either electromagnetic or acoustic technology, enabled a current-measuring capability to be incorporated into the drift object and for the movement of the object with respect to the water to be measured directly. Compact weather stations and drifting (or moored) meteorological buoys permitted reliable wind data collection at or near the drift object during even severe conditions. Records of leeway drift and leeway tracks are, as a consequence, much more accurate than in past records. More importantly, the variability of the record can be considered a reflection of the variability of leeway rather than of the noise in the data.

The data analyzed in this report were collected during a field experiment conducted offshore of Delaware Bay from 17 January 1998 through 1 February 1998. This experiment employed the modern methods and instrumentation described above. Leeway data were collected during eighteen leeway runs for a Person-In-Water wearing a Type I personal flotation device (PIW-I), a Person-In-Water wearing a survival suit (PIW-SS), a Windsurfer, a Sea Kayak, and a Wharf Box with 1- and 4-person loading. Leeway was

directly measured using either an attached or tethered current meter. Drift and wind data were analyzed to determine downwind and crosswind leeway speed as a function of wind speed adjusted to the 10-meter height. Statistics that provide a measure of the uncertainty or variability of the leeway drift were computed as inputs into Coast Guard Search and Rescue (SAR) planning tools.

RECOMMENDATIONS

Based upon analysis of the collected data, this report recommends leeway values to the search planner for the Wharf Box, the two configurations of PIWs, the Windsurfer, and the Sea Kayak (see Tables 5-1 through 5-9). The presentation of leeway values and the form in which they are used is dependent on the particular search planning application. In the case of manual search planning, the values found in Table 5-1 are recommended. The appropriate inputs for the presently used U.S. Coast Guard numerical SAR planning tool, CASP, are presented in Table 5-2. For the next generation of SAR planning tools that may use downwind and crosswind leeway components, Tables 5-3 through Table 5-9 provide the necessary coefficients and statistical measures.

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LIST OF ACRONYMS AND ABBREVIATIONS

a	Regression coefficient
abs	Absolute value
A/D	Analog to digital
ADCM	Acoustic Doppler Current Meter
b	Regression coefficient
c	Regression constant
CASP	Computer Assisted Search Planning
cm/s	Centimeters per second
CWL*	Crosswind Component of the Leeway Vector
deg	Degree
Dir	Direction
DWL*	Downwind Component of the Leeway Vector
EMCM	Electromagnetic Current Meter
GPS	(NavStar) Global Positioning System
HDOP	Horizontal dilution of position
hh:mm:ss	Hours:Minutes:Seconds
Hs	Significant wave height
Hz	Hertz (frequency)
IDCS	In-line Doppler Current Sensor
km	Kilometers
Lα	Leeway angle
L	Leeway vector
LKP	Last Known Position
m	Meters
m/s	Meters per second
max	Maximum
MHz	Megahertz (frequency)
min	Minute or minimum
n	Number of points used in a regression
NOAA	National Oceanic and Atmospheric Administration
N/A	Not available or not applicable
PFD	Personal Flotation Device
PIW	Person-In-Water
PIW-I	PIW wearing a Type I PFD
PIW-II	PIW wearing a Type II PFD
PIW-SS	PIW wearing a survival suit/exposure suit
R&DC	Research and Development Center
r^2	Coefficient of determination
RDF	Radio Direction Finder
RWD	Relative wind direction
SAR	Search and Rescue
Sec	Second
SLDMB	Self-Locating Datum Marker Buoy

$S_{y/x}$	Standard error of the estimate
s. dev.	Standard deviation as in Table 4-31
USCG	United States Coast Guard
UTC	Universal Time Coordinate
$\mathbf{W}_{\mathbf{10m}}$*	Wind speed vector adjusted to 10 meter height

*** Vector quantities are in bold type.**

CHAPTER 1

INTRODUCTION

1-1 BACKGROUND

A key element of a successful search is the accurate prediction of the total displacement of a SAR target from its estimated Last Known Position (LKP). For a search object located on the surface of the water, the total displacement is the vector addition of the sea surface currents and leeway. The US Coast Guard requires an accurate method to model the leeway component of total displacement in order to conduct efficient and successful SAR operations.

The concern for the effect of wind on survivor craft during SAR operations dates to a study conducted by Pingree (1944). Since that original study, attempts have been made to improve and refine leeway search guidance and to expand the variety of SAR objects that have leeway drift information available.

Before the advent of any accurate real-time open ocean navigation/positioning system the problems of determining leeway drift were enormous. For the leeway of a SAR object to be calculated, the position of the object must be known accurately and continuously, and the reference wind must also be known at the drift object position. Using celestial navigation or even LORAN-C this task is formidable. Add to that difficulty the task of converting the drift of drogues or the record of moored current meters to an approximation of the ocean current at the location of the drift object. Also add the difficulty of converting wind records to the reference wind for the drift object, and the task of estimating leeway becomes nearly impossible.

Beginning with the leeway studies in the early 1990's, technology dramatically changed our capabilities to measure leeway directly. Satellite-based navigation and communications enabled objects and instruments to be tracked with precision and for their data to be recovered even in cases of equipment loss. Small self-contained current meters, either electromagnetic or acoustic technology, enabled a current measuring capability to be incorporated into the drift object and for the movement of the object with respect to the water to be measured directly. Compact weather stations and drifting (or moored) meteorological buoys permitted the collection of reliable wind data at or near the drift object during even severe conditions. Consequently, records of leeway drift and leeway tracks are much more accurate than in past records. More importantly, the variability of the record can be considered a reflection of the variability of leeway rather than of the noise in the data.

An extensive background on leeway experiments and methods can be found in Allen and Plourde (1999).

For the search planner using manual methods, the components of leeway include leeway speed and leeway angle. Leeway speed is the speed at which the wind will push an object through the water. Leeway angle is the angle off the downwind direction that the object sails. Expressing leeway in terms of its downwind and crosswind components, instead of leeway speed and leeway angle, has advantages for interpretation of behavior and for ease of incorporation into numerical models.

Leeway as defined by the National SAR Manual is "that movement of a craft through the water, caused by the wind acting on the exposed surface of the craft." This definition of leeway is physically correct, but has two major operational shortcomings. Objects on the surface of the ocean are at the interface of two boundary layers where there is high vertical shear in the velocity profiles of wind and sea currents. Fitzgerald et al. (1993) proposed a revised leeway definition:

> *"Leeway is the velocity vector of the search object relative to the downwind direction at the search object as it moves relative to the surface current as measured between 0.3m and 1.0m depth caused by winds (adjusted to a reference height of 10m) and waves." (Fitzgerald, et al, 1993)*

This operational definition of leeway was used for presenting the results of this report.

This definition standardizes the wind and current reference levels for the measurement of the leeway of SAR objects. Both of these levels are readily available to the operational SAR planner. Most "sea level" wind products are adjusted to the 10 m height. The new Self-Locating Datum Marker Buoys (SLDMBs) are designed with drag elements between 0.3 m and 1.0 m depth (O'Donnell, et al, 1998).

In the leeway experiments conducted for this report, wind measurements are standardized to a reference level of 10 m by means of a model that uses the logarithmic near-surface profile for wind speed and accounts for the stability of the air in the boundary layer (Smith, 1998). Current meters attached to the leeway objects are used to measure relative currents at the object location and are set to collect current data between 0.3 m and 1.0 m.

1-2 SCOPE

Leeway experiments conducted by the USCG R&D Center during September and October 1997 and January and February 1998 continued a series of leeway experiments that began with a joint U.S. Coast Guard/Canadian Coast Guard experiment in 1992 (Fitzgerald, et al, 1993) and a follow-on experiment in 1993 (Fitzgerald et al, 1994). This series of leeway experiments and field data collection were the first such experiments to employ state-of-the-art technology such as Global Positioning System (GPS) navigation, reduced size electromagnetic or acoustic current meters, and small on-board weather stations. The cooperation with the Canadian Coast Guard continues and is formalized under a Joint Research Project Agreement (JRPA) #5. The agreement enables a sharing of fieldwork, data analysis, interpretation, and publication.

This series of leeway experiments differs from earlier leeway experiments because of improved technology. As the series developed, improved techniques progressed from concepts to proven field practices. The single most significant advance was the use of small size internally recording current meters of the electromagnetic or acoustic type. These current meters were small enough to be attached directly to the search object so that the leeway of the object could be measured directly as a relative current velocity rather than being inferred from the object position and a remotely measured current. Also, the ability to collect meteorological data continuously at or near the drift object greatly improved the relationship of these data to the particular leeway object. Leeway objects capable of internally recording measurements of wind and current along with satellite positioning and telemetry permitted greater data recovery and the ability to gather data during periods of severe weather.

The September/October 1997 leeway field experiment, conducted offshore near Fort Pierce, FL, evaluated the following leeway drift objects:

1. PIW-I; Person-In-Water (PIW) in Personal Floatation Device (PFD), Type I
2. PIW-II; PIW in PFD Type II
3. PIW-SS; PIW in survival suit
4. Sailing Vessel
5. Motor Vessel

The Fort Pierce experiment was designed to serve as a testbed for new instrumentation and configurations of drift objects that had never before been evaluated using the direct measurement of leeway technique. The data collected during the Fort Pierce, FL experiment were not included in the analysis for this report both because of insufficient data quantities and because of data collection problems related to using new drift object types. Specifically the relationship of the measured wind to the leeway speed for the PIW-I and PIW-SS presented a situation where leeway speed decreased with increasing wind speed. As a result modifications to the wind measurement protocol were developed for the next experiment series.

The January/February 1998 leeway field experiment conducted offshore of Delaware Bay evaluated the following leeway drift objects:

1. PIW-I
2. PIW-SS
3. Sea Kayak
4. Wharf Box/ice chest
5. Windsurfer

Sufficient data were collected during the leeway experiments to conduct a leeway analysis for the PIW-I, PIW-SS, Windsurfer, Sea Kayak, and Wharf Box (Table 1-1). For this report, drift and wind data were analyzed for downwind leeway speed and crosswind

leeway speed as a function of wind speed and direction. Statistics, indicative of the variability of the leeway drift response to wind, were computed as a basis for Search and Rescue (SAR) object dispersion calculations.

Table 1-1. Leeway Data Quantities Offshore Delaware Bay January/February 1998

Leeway Object Type	Leeway Run Numbers	Data Quantities (hh:mm)
PIW-I	121 & 126	23:36
PIW-SS	119, 122 & 125	59:06
Windsurfer	115, 118 & 123	61:18
Sea Kayak	113, 116 & 120	65:00
Wharf Box (light load)	114 & 117	52:18
Wharf Box (heavy load)	127 & 128	49:18

Chapter 1 provides background material and a review of the methods used in previous leeway experiments for measuring leeway, currents, and winds. The methods and leeway craft used during this experiment are described in Chapter 2. A summary of data reduction and a review of the statistical methods used are presented in Chapter 3. Statistical models for leeway craft behavior are presented in Chapter 4. Chapter 5 contains recommendations, conclusions, and suggestions for future work in this area.

CHAPTER 2

THE EXPERIMENT

2-1 EXPERIMENTAL DESIGN

Leeway experiments have the goal of isolating the effects of wind on a floating object from the effect of current. In the absence of wind the floating object will follow the average trajectory of the water which surrounds it, complicated only by the shear in the current over the draft of the object. As the wind velocity increases the situation complicates rapidly. The forces exerted on the object are not only the drag forces in the direction of the wind and the direction of the current, but also the lift drag forces and the wave related drag forces that act at right angles to the direct drag forces. The lift forces can have a dramatic impact on the direction and speed of drift. The lift forces are strongly dependent on the relative direction and magnitude of the air and water forces as well as on the shape of the drifting object (Hodgins and Hodgins, 1998).

In the experiments reported on here, leeway was directly measured using either an attached or tethered current meter. The current meters used in the direct measurement of leeway were selected so that their cross-sectional area added a minimum of water drag to the leeway objects. The leeway drift runs were started near a moored meteorological buoy that measured winds and wave height. Additional wind measurements were collected aboard the leeway objects when their size made it possible. Surface current measurements were made using a current meter attached to the float line of the meteorological buoy to provide Eulerian surface current information (Florida experiment only). GPS data loggers, on some drift objects, were used to measure total displacement of the leeway craft. Transmitting Argos beacons were aboard each craft or object to aid in recovery.

Fitzgerald, et al., (1993) was the first to use the direct method for measuring leeway. The direct method uses a current meter attached to a search object to measure the relative motion of the object through the water at the depth of the current meter. Fitzgerald et al. (1993) validated the direct method in a comparison with an older, traditional indirect method. In the traditional method a velocity estimate from an array of surface drifters was subtracted from an estimate of the drift object velocity over the ground to obtain estimates of the object velocity through the water. The direct method, validated by Fitzgerald, et al. (1993), was used to measure leeway in this experiment.

2-2 FLORIDA FIELD TEST

The USCG R&D Center conducted a leeway drift experiment off the East Coast of Florida in the vicinity of Fort Pierce, FL. The experiment ran from 16 September through 3 October 1997. Leeway objects of the types PIW-I, PIW-II, PIW-SS, Sailing Vessel, and Motor Vessel were involved in the experiment. The data from this field experiment were

not included in the analysis for this report. The types of drift objects and their instrumentation were new to the experimenters. The development of drift object configuration, deployment techniques, and data recovery methods were the primary goals of this experiment series.

2-3 DELAWARE FIELD TEST

The leeway experiment that provided the data for this study was conducted offshore of Delaware Bay (Figure 2-1). The experiment ran from 17 January through 1 February 1998. Leeway objects of types PIW-I, PIW-SS, Sea Kayak, Wharf Box, and Windsurfer were involved in the experiment. Sufficient data were collected on all of the types of leeway objects used during the experiment to support analysis. Command, control, and communications were maintained onboard the workboat, R/V CAPE HENLOPEN by the R&D Center and their contractor, A&T, Inc. The University of Delaware, out of their branch at Lewes, DE, operated the R/V CAPE HENLOPEN.

2-4 CURRENT DATA COLLECTION SYSTEMS

2-4.1 InterOcean S4® Electromagnetic Current Meter (EMCM)

The InterOcean S4® EMCM measures near field currents by sampling the changes in orthogonal magnetic fields produced by the motion of water relative to the instrument. The InterOcean S4® EMCMs sampled at 2 Hz, and were vector averaged over 10-minute periods. An internal flux-gate compass converted the two orthogonal components of velocity to magnetic north and east coordinates. The raw directions of currents from the S4® EMCMs were adjusted for the magnetic variation and then rotated 180 degrees to account for the fact that the relative current is in the opposite sense from the leeway direction. Two tilt sensors in the S4® EMCMs were used to apply, at 2 Hz, the cosine correction for the tilt angle to the current speed. Temperature at 0.75m depth was also sampled every 10 minutes. The S4® EMCMs are calibrated yearly by InterOcean.

An InterOcean S4® EMCM was tethered to the SAR object to measure velocity relative to the water. Each S4® EMCM was suspended in a stainless steel frame at 0.75m depth; thus the water reference level for currents in this report is 75 cm. The frame was attached to a float sized to nearly match the wind-induced drift of the leeway craft. This method minimizes the drag on the leeway craft imposed by the current meter (see Fitzgerald et al. (1993), Appendix C). The frame, with S4® EMCM, was attached by a 15m line to the pivot point of the leeway craft to minimize steering effects of the attached current meter on the search object.

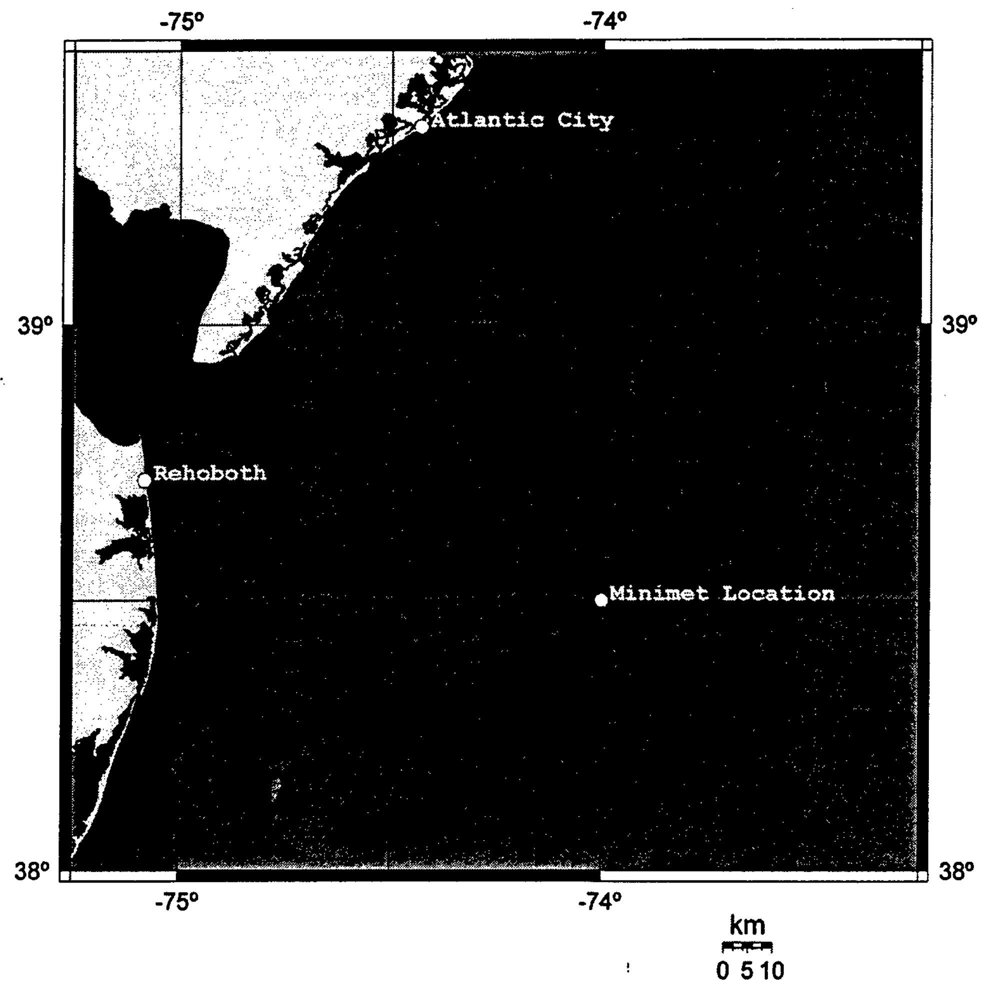


Figure 2-1. **Leeway Drift Experiment Area, Delaware Bay Offshore, January/February1998**

2-4.2 SonTek Argonaut® Acoustic Doppler Current Meter (ADCM)

The SonTek Argonaut® ADCM measures ocean currents by averaging the acoustic Doppler shift in a volume of water below the current meter caused by the relative motion of water and instrument. Water volume sampled could be user defined from 0.5m to 15.0m below the current meter. For this series of experiments, the volume selected was 0.7m to 1.5m from the current meter. The ADCM was equipped with a compass accurate to ±2° for calculating true current direction. A tilt sensor with an accuracy of ±1° was incorporated into the ADCM and its output was used for calculating velocity in Earth coordinates. Sampling rates were 0.1 Hz or lower. The ADCMs were factory calibrated and had an accuracy of ±0.5 cm/s or 1% of the measured velocity.

The Argonaut® ADCM was hard mounted to a leeway object and pointed downward. The ADCM was configured so that the water volume sampled was centered on a 1.2 m depth. The attachment method was designed to have minimal effect on object leeway.

2-4.3 Aanderaa In-line Doppler Current Sensor (IDCS)

The Aanderaa IDCS employs four piezoceramic acoustic transducers that use an acoustic Doppler shift, to measure the velocity of particles carried in the water. The volume of water sampled is located horizontally from the IDCS at a distance of 0.5m to 2.0m from the transducers. Current direction was computed from the two orthogonal components and referred to magnetic north by means of an internal Hall-effect compass. The current was corrected for tilt internally without tilt being reported as a separate parameter. Accuracy of the velocity was ±2 cm/s and ±5° for tilt angles less than 15°. The IDCSs were factory calibrated.

The Aanderaa IDCSs were attached directly to the leeway object and below it so that the IDCS sampled a water layer centered on the 70 cm depth. The attachment was designed to have minimal effect on object leeway.

2-5 WIND DATA COLLECTION SYSTEMS

The standard method for measuring wind during this experiment was to use onboard wind monitoring systems calibrated to a moored Coastal Climate MiniMet® buoy (see Fitzgerald et al. (1993) and (1994) and Allen (1996)). The MiniMet® buoy's R. M. Young anemometer was mounted at a 3m height. The MiniMet® buoy sampled environmental data at a 1 Hz rate for a 10-minute period. During the experiments the larger leeway craft were equipped with R. M. Young anemometers. During the Fort Pierce leeway drift test only the MiniMet® winds were used. In the Delaware test, however, the local winds recorded on the WeatherPak® mounted on the Wharf Box were used in the analysis. The MiniMet® Buoy and Weather Pak® recorded the data in Table 2-1 on a continuous cycle.

The MiniMet® buoy wave data included significant wave height and wave energy spectrum from a Datawell® gimbaled heave sensor. Wave height was sampled at 1 Hz for 512 seconds every 10 minutes.

R. M. Young anemometers were calibrated, prior to the fieldwork, for both speed and relative bearing. The compasses in the WeatherPak® and the MiniMet® were also calibrated prior to the experiment to determine deviations. The anemometers were then paired with a WeatherPak® or the MiniMet® buoy to minimize error as a function of heading. A second calibration was conducted of the anemometer - A/D converter system. The MiniMet® compass deviation corrections were applied at the 1 Hz sampling interval. Instrument error for wind direction from the MiniMet® and Weather Pak® wind monitoring systems was estimated to be $\pm$ 2°.

Table 2-1. Leeway Environmental Data Collection Systems - Data Descriptions

MiniMet® Meteorological Buoy	WeatherPak® Meteorological Station
Date and time, at end of sampling period	Date and time, at end of sampling period
Wind speed – 10 min. vector average and standard deviation	Wind speed – 10 min. vector average and standard deviation
Wind direction (magnetic, wind from) – 10 min. vector average and standard deviation of wind direction.	Wind direction (magnetic, wind from) – 10 min. vector average and standard deviation of wind direction.
Wind vane bearing – 10 min. vector average and standard deviation	Wind vane bearing(degrees relative to bow) – 10 min. vector average and standard deviation
Compass heading – 10 min. vector average and standard deviation of compass heading	Compass heading – 10 min. vector average and standard deviation of compass heading
Wind speed – 10 min. scalar average and standard deviation of wind speed	Wind speed – 10 min. scalar average and standard deviation of wind speed
Wind maximum (gust) – 5 sec. average	Wind maximum (gust) – 5 sec. average
Time(sec.) of gust from start of 10 min. sample	Time(sec.) of gust from start of 10 min. sample
Water temperature at 2 m depth	
Internal buoy temperature	Internal WeatherPak® temperature
Air temperature at 3 m height	Air temperature at anemometer height
GPS Time (hh:mm:ss)	GPS Time (hh:mm:ss)
Latitude from GPS receiver	Latitude from GPS receiver
Longitude from GPS receiver	Longitude from GPS receiver
HDOP	HDOP
Barometric pressure at 3 m height	
Pitch – 10 minute mean, standard deviation, and maximum	Pitch –10 minute mean, standard deviation, and maximum
Roll –10 minute mean, standard deviation, and maximum	Roll – 10 minute mean, standard deviation, and maximum
Buoy battery voltage	WeatherPak® battery voltage
Checksum	Checksum
Significant Wave Height (meters)	
Period of maximum wave energy (sec)	
Spectral wave energy 31 frequency bands (m^2/Hz)	

Raw Wind data were rotated (based on local magnetic deviation) from magnetic to true coordinates, and then rotated 180 degrees to convert the direction from the meteorological to the oceanographic convention. This generated the apparent wind. The apparent wind was not corrected for the motion of the leeway craft. Apparent wind was then converted to corrected wind by adding the drift speed of the leeway object. Corrected wind direction for each leeway run was rotated to match the winds from the MiniMet® buoy and was then called the adjusted wind. The MiniMet's® anemometer had a clean airflow, with minimum buoy motion, providing a very stable measurement of wind direction. In the final step, wind speed of the adjusted wind was modified from the anemometer height to the 10m reference height using the algorithm described by Smith (1988). The wind vectors adjusted to the 10m reference height are referred to, in this report, as $\mathbf{W_{10m}}$.

The MiniMet® buoy winds were qualitatively compared to winds measured by NOAA Buoy #44009 (meteorological buoy) to look for glaring inconsistencies, frontal passage or instrument malfunction. Wind Speed adjusted to 10m height from the MiniMet® buoy agrees relatively well with the NOAA winds through the entire record; see Figure 2-2.

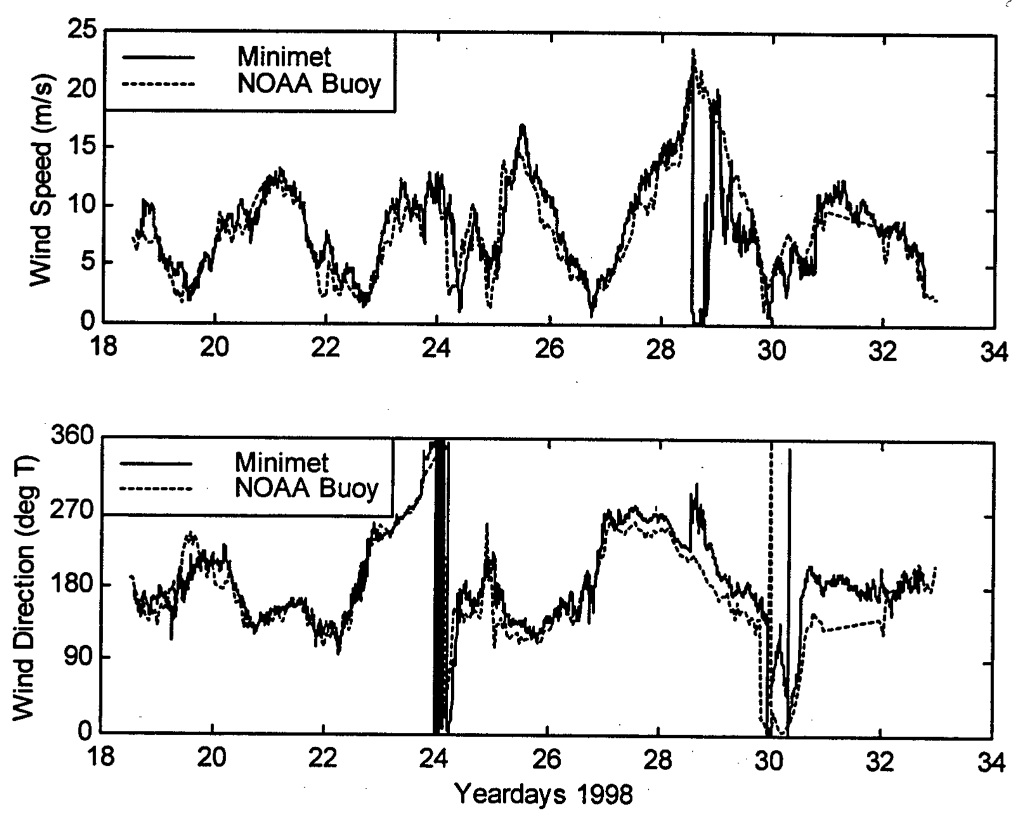


Figure 2-2. Time Series of (A) Wind Speed Adjusted to 10m height and (B) Wind Direction from MiniMet® Buoy and NOAA Buoy – Delaware Bay Offshore

2-6 MEASUREMENT OF DRIFT

Drift is the movement of the leeway object over the ground. Onboard the wharf box was a six channel Trimble Global Positioning System (GPS) receiver connected to the WeatherPak®. The GPS position and time were stored at 10-minute intervals. The GPS receiver, WeatherPak®, and batteries were housed in a waterproof case. The GPS antenna was mounted onboard the leeway craft and connected through a watertight bulkhead connection in the waterproof case to the GPS receiver.

GPS/Argos beacons were onboard all other targets. The Argos system provides positions based on a Doppler shift of the transmission, usually at intervals of 1-2 hours during a satellite pass. The Argos system also is used to transmit stored half-hourly positions from the GPS receiver.

2-7 MEASUREMENT OF SEA CURRENTS

Eulerian sea currents were measured by a S4® EMCM attached to MiniMet's® surface float line (Florida experiment only), at 0.75 m depth. The float line isolated the S4® EMCM from the mooring line strumming interference and influence of the MiniMet® buoy hull. The float line follows the surface waves that have periods greater than 4 seconds. The S4® EMCM sampled at 2 Hz and was averaged over 10 minute periods continuously. A cosine correction for tilt was applied to the horizontal currents using the two vertical tilt sensors. Sea surface temperature at 0.75 m depth was sampled every 10 minutes. The horizontal currents were corrected for the horizontal motion of the MiniMet® about its anchor.

2-8 CRAFT RECOVERY SYSTEM

Aboard the leeway objects were GPS/Argos transmitters. Argos positions were provided through Service Argos. Imbedded in the Argos message was a GPS position that could be obtained by means of a decoding program. For local relocation, a Gonio® 400 Radio Direction Finder (RDF) aboard the ship was tuned to the Argos System frequency (401.065 MHz) to receive and download the object's position.

2-9 TEST CRAFT

2-9.1 Person-In-Water (PIW)

Modified plastic department store mannequins were used to simulate three types of leeway drift objects. One mannequin was modified for use with Personal Floatation Devices (PFD) of Type I and Type II (Figure 2-3). This mannequin was ballasted so that it floated in an upright, seated position as a person in a life vest would normally float. The Type I PFD was an Offshore life jacket model with a minimum buoyancy force of 24 lbs. The Type II PFD was a Near-shore buoyant vest model with a minimum buoyant force of 15.5 lbs. Both types of PFDs were for persons weighing more than 90 lbs. The other mannequin was ballasted for use with a survival suit and floated in a nearly horizontal

orientation (Figure 2-4). The modified mannequin outfitted with a Type-I PFD was designated PIW-I, the one with a Type-II PFD as PIW-II, and the one with a survival suit as PIW-SS.

Prior to field deployment, the simulated PIW leeway objects were floated in a swimming pool alongside persons outfitted with the same types of survival gear. The leeway drift objects were modified to have the same orientation and the same above and below water proportions as the human subjects.

The orientation and buoyancy of various PIW drift objects were field checked during the Fort Pierce, FL experiment by having an experimenter floating alongside the PIW drift object. The experimenter was equipped either with a Type I PFD or survival suit as appropriate. During the time the experimenter was in the water a visual comparison was made of the respective float characteristics of the mannequin and the experimenter. This visual comparison satisfied the authors that the mannequin PIW was a realistic substitution for an actual PIW.

The mannequin for PIW-I and PIW-II had an Aanderaa IDCS mounted from the body such that the current meter measured the movement of a volume of water horizontal from the instrument centered at a 70 cm depth. The mannequin for PIW-SS was configured so that its Aanderaa IDCS, while floating in a nearly horizontal position, was oriented so that it also measured a horizontal volume of water centered at a depth of 70 cm.

The PIW simulation mannequins were each instrumented with a head-mounted GPS/Argos antenna and with the GPS receiver and Argos transmitter mounted in the body cavity. The mannequins had a large number of holes drilled in them so that they would sink quickly to the desired level.

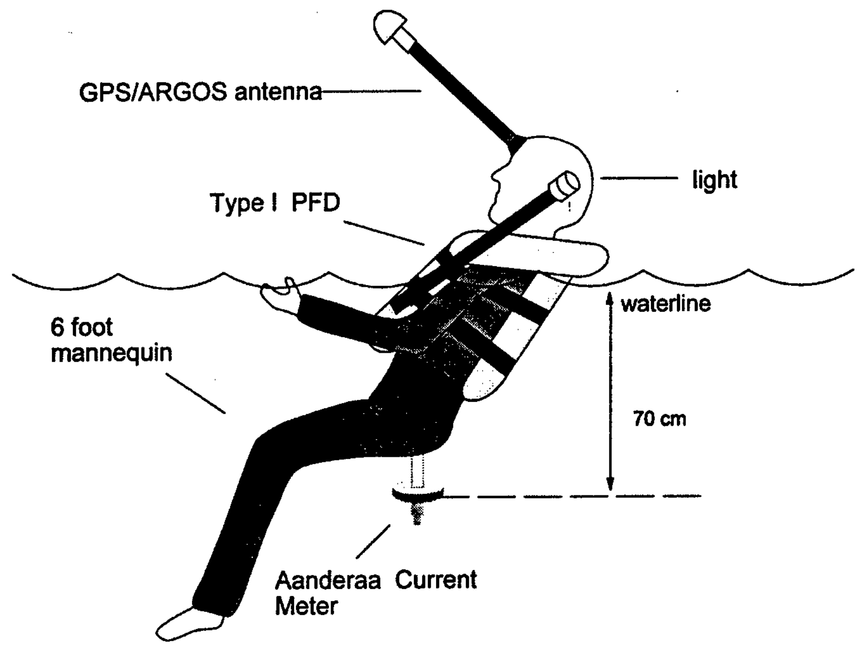


Figure 2-3. Simulated Person-In-Water Wearing a Personal Flotation Device

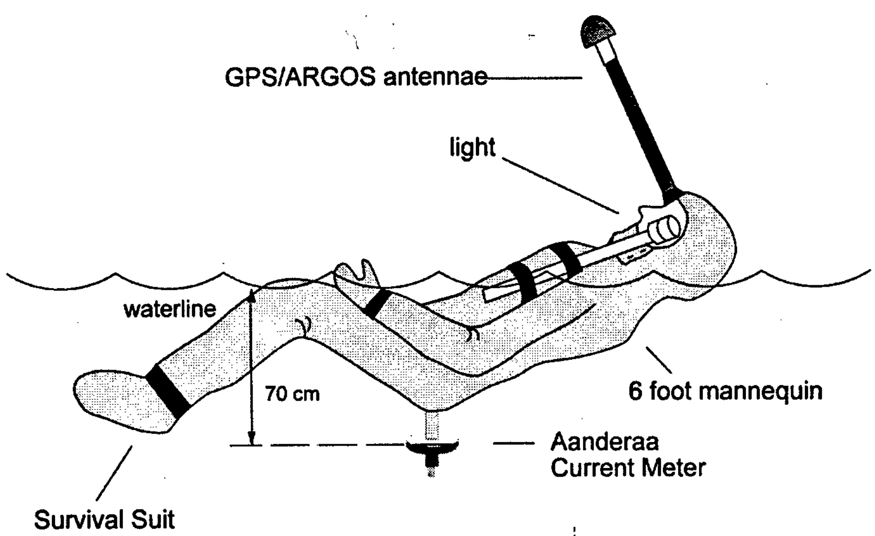


Figure 2-4. Simulated Person-In-Water Wearing a Survival Suit

2-9.2 Windsurfer

A popular type of beginner/intermediate Windsurfer known as a high buoyancy/high volume type (approximately 200 liters), but not equipped with a mast and sail (Figure 2-5), was used to simulate a class of leeway drift objects frequently used in coastal areas. In

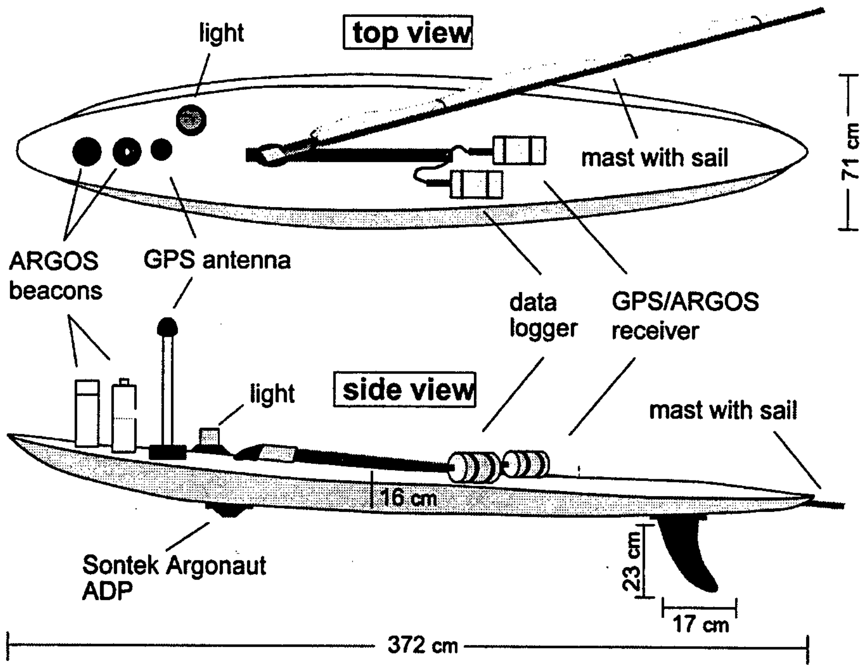


Figure 2-5. High Buoyancy/High Volume Windsurfer

these tests a mannequin, simulating an operator, was attached to the stern portion (Figure 2-6). Sail and mast were not used during these trials because experienced windsurfers in distress detach these items. The Windsurfer used had a length of 372 cm, a width of 71 cm, and a hull thickness of 16 cm. The dagger board was not deployed in the down position as doing so would cause the Windsurfer to capsize and lift the current meter out of the water. The Windsurfer, however, was equipped with a 23 cm x 17 cm fin-shaped skeg at the stern.

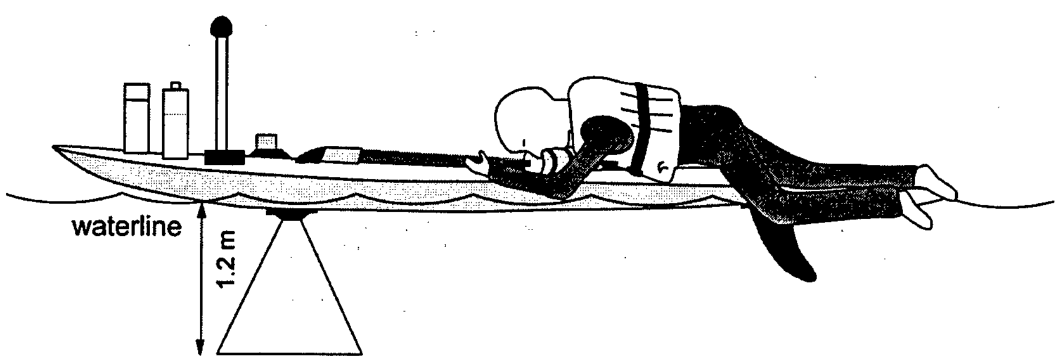


Figure 2-6. Windsurfer Waterline as Deployed during Leeway Experiments

The Windsurfer was equipped with a GPS/Argos beacon for positioning with a second emergency Argos beacon on the underside. The second Argos beacon was mounted upside down through the hull and contained a mercury switch so that it operated only when the Windsurfer was completely capsized. A well in the center of the Windsurfer housed a SonTek Argonaut® ADCM that measured the relative current in a volume of water centered at approximately 1.1 m below the hull.

2-9.3 Sea Kayak

A plastic sea kayak (Figure 2-7) was employed as a drift object on three leeway runs. On the two leeway runs analyzed in this report, a mannequin on the stern was used to simulate a distressed offshore kayaker experience (Figure 2-8). The position of the distressed and fatigued on the sea kayak was based on discussions with the editors of Sea Kayak magazine and on a description in Broze and Gronseth (1997). The sea kayak had an overall length of 423 cm, a hull length of 411 cm, a beam of 54 cm, and a hull thickness of 19 cm. The sea kayak was allowed to swamp to adjust its floatation level to a realistic level for a distressed kayak. The kayak had an Aanderaa IDCS mounted through the bottom that was used to measure the current relative to the hull in a volume of water centered at 70 cm depth. The paddle was attached to the topside of the hull. As with the other leeway drift objects the sea kayak had a top mounted GPS/Argos beacon and a bottom mounted Argos beacon on a mercury switch for emergency recovery.

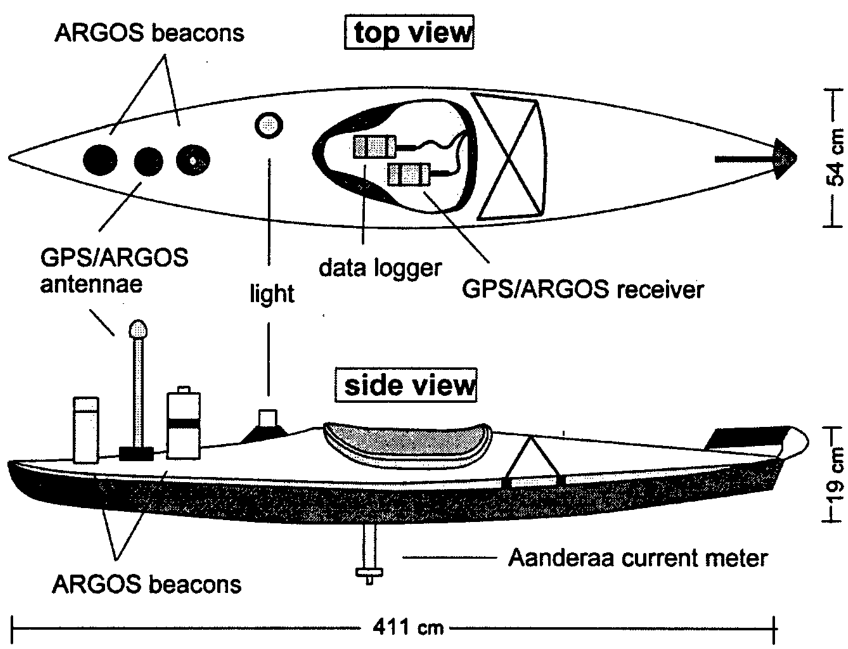


Figure 2-7. Sea Kayak

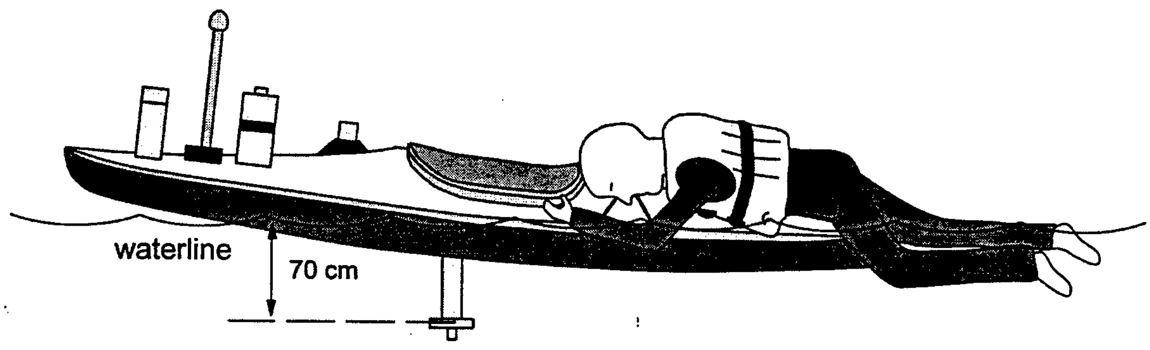


Figure 2-8. Sea Kayak Waterline as Deployed during Leeway Experiments

2-9.4 Wharf Box

A rectangular, floatable plastic utility container (Figure 2-9), measuring 146 cm x 116 cm x 84 cm, was used in the experiments to simulate the Wharf Boxes found on many commercial fishing boats. The boxes have an internal volume of approximately 1.2 cubic meters for storing fish and/or ice onboard. In a distress situation the boxes are often used as a last resort lifesaving craft. The container was foam filled for the drift experiments with cavities cut into the foam to allow space for instrumentation and for weights which would simulate either a light load (one-person) or a heavy load (four-persons). The waterline for the one-person and four-person loads are illustrated in Figure 2-10. The movement of the wharf box relative to the surrounding water was measured by an S4® current meter. The S4® was mounted in a frame suspended from a float that was tethered to a bridle attached to the hull of the box. A WeatherPak® was mounted on the wharf box on a 34 cm high pipe to measure local winds. The anemometer height was 1.8 to 1.9 m above the water line. A GPS receiver was incorporated in the WeatherPak®. The wharf box had three onboard Argos transmitters. One was incorporated into the WeatherPak® as a data/positioning link, one was on the S4® frame and was used as a data/positioning link, and the third was a bottom mounted unit on a mercury switch to be used for emergency object recovery.

The Wharf Box was tested prior to going to the field by placing it in a swimming pool and loading it variously with one and four persons to simulate a distress situation. The series of pool tests were used to determine the orientation and waterline of the Wharf Box under these emergency conditions. The instruments were then installed on the box and its orientation and waterline adjusted with weights so that it matched the emergency condition appearance.

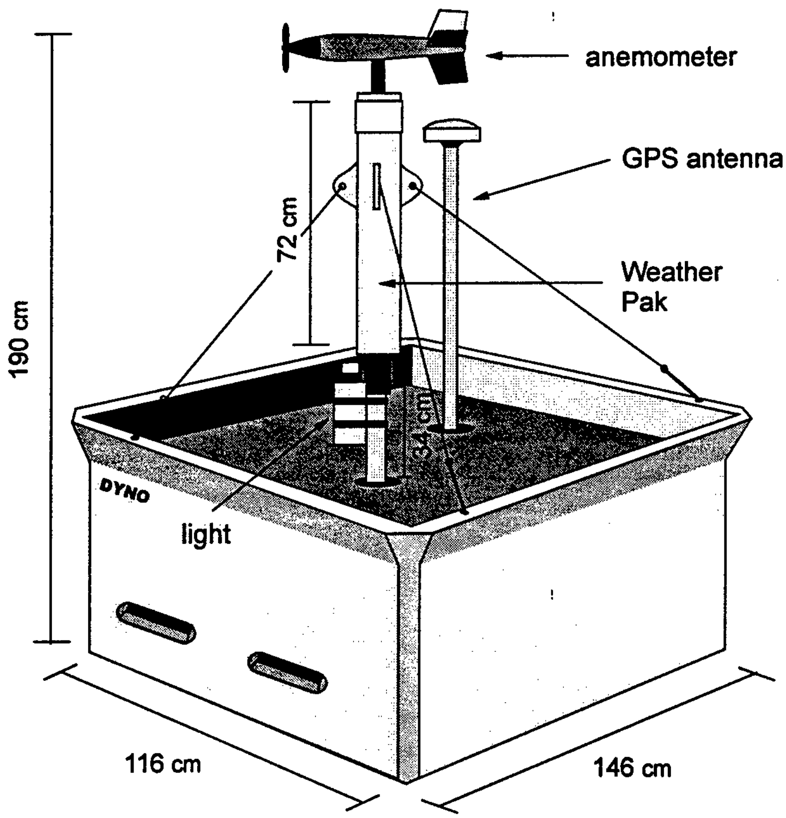


Figure 2-9. Wharf Box

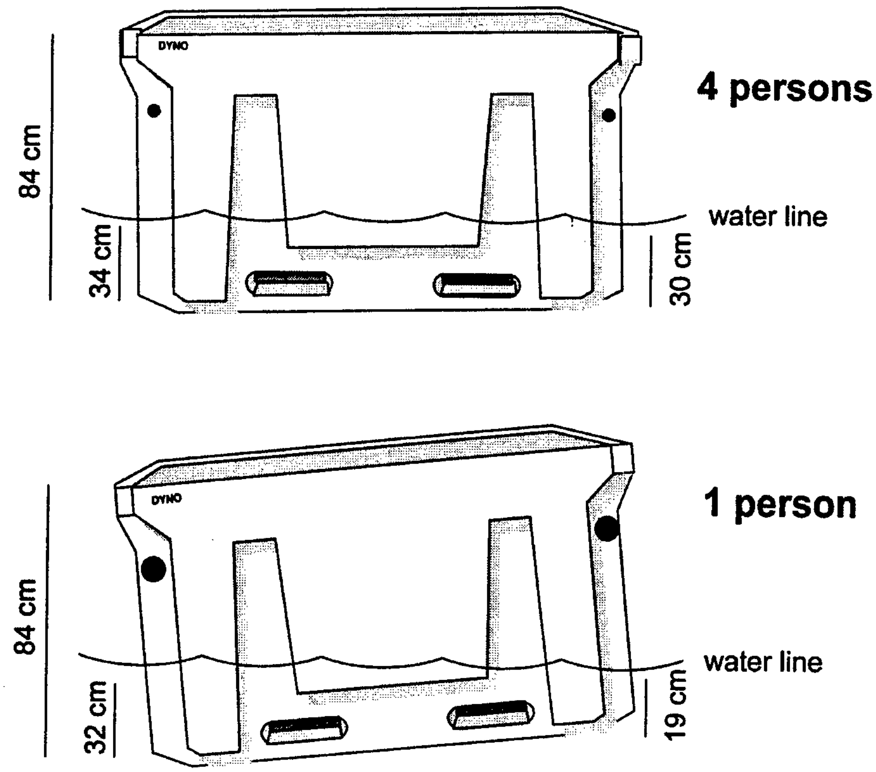


Figure 2-10. Wharf Box Waterline as Deployed during Leeway Experiments for 4 Person and 1 Person Loads

CHAPTER 3

DATA PROCESSING

3-1 DEFINITIONS OF PARAMETERS

Relative Wind Direction (RWD) - The direction from which the wind blows, measured in degrees, in reference to a chosen axis or reference point of the test craft (Figure 3-1). A wind from the right of the selected axis or reference point is positive and from the left is negative.

Leeway Angle (Lα) - Leeway drift direction minus the direction towards which the wind is blowing. A drift to the right of downwind is positive and to the left of downwind is negative (Figures 3-1). This is the same convention as for Relative Wind Direction. A leeway angle of 0 degrees indicates that the craft drifts directly downwind.

Leeway Speed (|L|) - The magnitude of the leeway velocity (Figure 3-2). Leeway speed is always positive. Leeway speed and leeway angle form the angular and distance coordinates of the polar coordinate system for the leeway velocity vector.

Downwind (DWL) and Crosswind (CWL) Components of Leeway - The components of the leeway velocity vector expressed in rectangular coordinates relative to the wind velocity vector ($\mathbf{W_{10m}}$) (Figure 3-2). The two components of leeway can be positive or negative. However, as a practical matter, the downwind component of leeway is almost always positive. The crosswind component is the divergence of the SAR craft from the downwind direction. Positive crosswind components are a divergence to the right of the wind and negative crosswind components are a divergence to the left of the wind. The clear advantage of using crosswind components of leeway, rather than leeway angle, to express the divergence of SAR craft from the downwind direction comes at low wind speeds. Since crosswind components of leeway are multiplied by wind speed, the scatter in the crosswind component at low wind speeds is reduced compared to the scatter of leeway angles. The net result is that statistical regressions of the components of leeway can be directly implemented in numerical search planning tools.

Leeway Rate - Leeway speed (|**L**|) divided by the wind speed adjusted to the 10 m reference level ($\mathbf{W_{10m}}$). Taking into account that the units of |**L**| are cm/s and the units of $\mathbf{W_{10m}}$ are m/s, the result appears as a percentage of the wind speed.

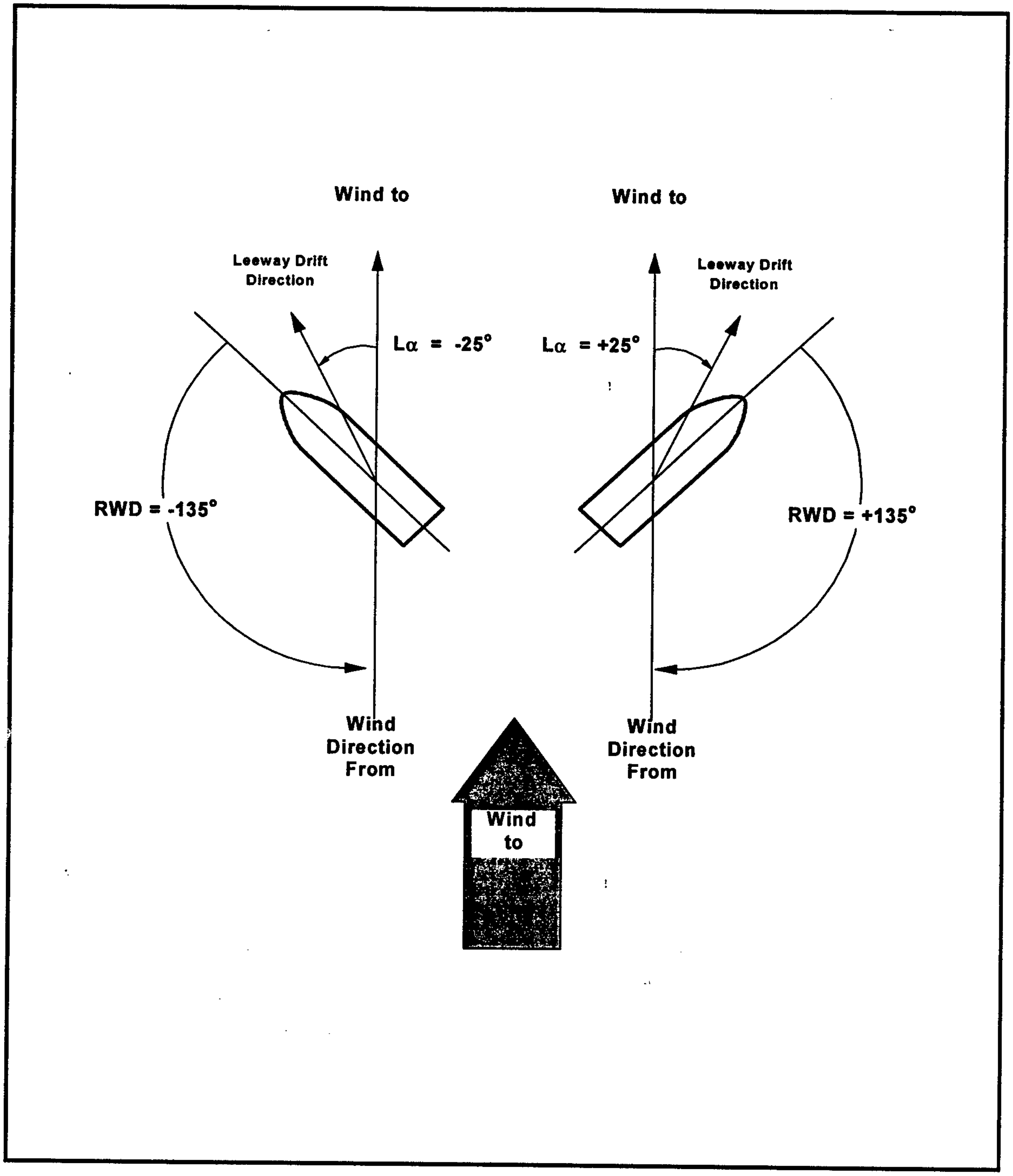
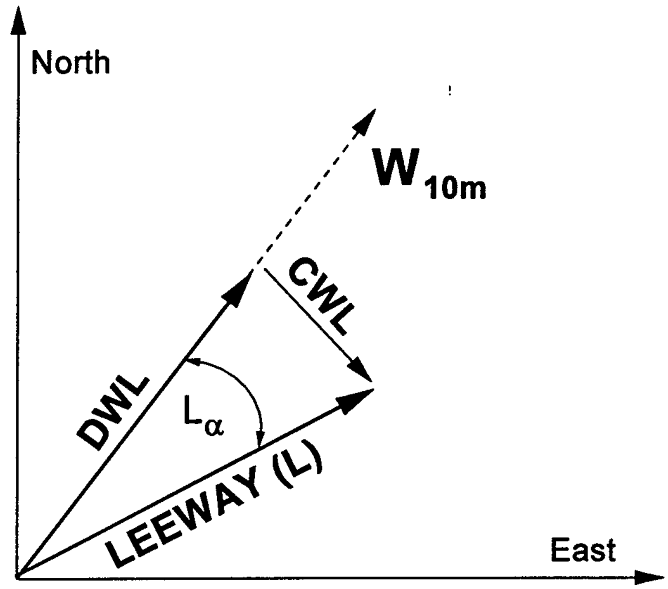


Figure 3-1. Relationship between Relative Wind Direction (RWD) and Leeway Angle (Lα).



$\mathbf{W_{10m}}$= Wind velocity vector adjusted to 10 m height,

L = Leeway vector,

$L\alpha$ = Leeway angle,

$$\frac{|\mathbf{L}|}{|\mathbf{W}_{10m}|} = \text{Leeway rate,}$$

$$\mathbf{DWL} = |\mathbf{L}|\sin(90^\circ - L\alpha) = \text{Downwind Leeway component,}$$

$$\mathbf{CWL} = |\mathbf{L}|\cos(90^\circ - L\alpha) = \text{Crosswind Leeway component.}$$

Figure 3-2. Relationship between the Leeway Speed and the Downwind and Crosswind Components of Leeway

3-2 ANALYSIS METHODOLOGY

3-2.1 Introduction

Analysis methods for leeway data sets are hierarchically dependent upon the quantity and quality of the leeway and wind data available for analysis, as shown in Table 3-1. (1) At

the lowest level, when the data are limited to just a few pairs of leeway speeds and wind speeds all at essentially the same wind speed, the analysis is limited to determining a mean leeway rate. (2) When more data pairs are collected, but the range of wind speed is limited, constrained linear regression may be calculated. (3) When the data set is large enough to include leeway speeds collected over a larger range of wind speeds, the analysis can include both unconstrained and constrained regressions of leeway speed on wind speed. Time series of leeway rates are also possible. (4) When the data set includes accurate measurements of leeway and wind direction collected over a range of wind speeds, regressions can be performed on the downwind (**DWL**) and crosswind (**CWL**) components of leeway versus wind speed. Since **CWL** can be either positive or negative, an assumption will be made (specifically, that **CWL** is symmetrical about the downwind

Table 3-1. Hierarchy of Methods for Leeway Data Analysis

	Available Leeway and Wind Data				
Analysis that can be performed	**Limited # of Data, at limited Wind Speed (1)**	**Limited Range of Wind Speeds (2)**	**Range of Wind Speeds (3)**	**Wind Direction and Range of Wind Speeds (4)**	**Multi-Drift Runs over a Range of Wind Speed with Direction (5)**
Leeway Rate	YES (mean)	YES (mean)	YES (time series)	YES (time series)	YES (time series)
Leeway Speed vs. W_{10m} (Constrained)	NO	YES (preliminary)	YES	YES	YES
Leeway Speed vs. W_{10m} (Unconstrained)	NO	NO	YES	YES	YES
Leeway Angle	NO	NO	NO	YES	YES
DWL vs. W_{10m}	NO	NO	NO	YES	YES
CWL vs. W_{10m}	NO	NO	NO	YES (assume symmetry about the downwind direction)	YES (determine symmetry / non-symmetry)

direction) when fitting regression of **CWL** versus wind speed. An analysis of leeway angle is also possible. (5) When the data set includes multiple drift runs, the symmetry of **CWL** can be tested with piece-wise regressions of the **CWL** versus wind speed to fully characterize the behavior of that leeway craft. This analysis does not require the assumption that the leeway drift of the test craft is symmetrical about the downwind direction.

The data available for analysis from the 1997/98 leeway experiments (see Sections 3-3 and 3-5) provided leeway data sets sufficient to conduct a full analysis (Table 3-1). This analysis included: regression of leeway speed on $\mathbf{W_{10m}}$, analysis of leeway angle, and finally regression of **DWL** and **CWL** on $\mathbf{W_{10m}}$ but without assuming symmetry about the downwind direction of **CWL** except in the case of PIW-SS.

3-2.2 Regression Methods

The definitions and analysis methods follow Allen (1996). Two linear regression models of leeway speed and both components (downwind and crosswind) of leeway on wind speed were used in this analysis. One regression model was unconstrained with respect to leeway speed at zero wind speed and the second was constrained through the origin so that the leeway speed was forced to be zero at zero wind speed:

$$\text{Leeway} = a + b * \mathbf{W_{10m}} \qquad (3\text{-}1)$$

(Linear regression, unconstrained)

$$\text{Leeway} = b * \mathbf{W_{10m}} \qquad (3\text{-}2)$$

(Linear regression, constrained through zero)

where: Leeway represents either leeway speed, downwind component of leeway, or the crosswind component of leeway; $\mathbf{W_{10m}}$ is the wind speed adjusted to the 10 meter reference height; and "a" and "b" are regression coefficients.

Tables in Chapter 4 contain the regressions of leeway speed and the downwind and crosswind components of leeway on $\mathbf{W_{10m}}$. Each table contains the number of samples (#), the y-intercept (a) and the slope of the regression line (b), the coefficient of determination or percent of the variance of leeway explained (r^2) by the model, the standard error of the estimate ($S_{y/x}$), and the range of wind speeds. The y-intercept (a) is in *cm/s*, the slope (b) is in [(*cm/s*)/(*m/s*)] which is *percent*, and variance explained (r^2 x 100 = *percent* variance explained).

An r^2 provides a measure of the percentage of the variance of leeway about the mean value of leeway in the unconstrained case that is explained by the linear regression model including $\mathbf{W_{10m}}$ as an independent variable. To provide the reader with a qualitative measure for interpreting the coefficient of determination (r^2), values between 0.80 and 1.00 are considered an excellent fit to the model, values between 0.60 and 0.79 a good fit, values between 0.40 and 0.59 a fair fit, values between 0.20 and 0.39 a poor fit, and values less than 0.19 are considered no better than the mean of the leeway speed data. This qualitative description roughly follows that used by Nash and Willcox (1991)

The coefficient of determination (r^2) was also computed for the cases in which the regression line was constrained through zero. For this case the variation between the data and the model might actually be greater than it is between the data and the mean, thus producing a value of r^2 that is negative. The result is that there is no r^2 for the constrained

model has no clear physical meaning. It still provides some insight into the appropriateness of the model to use $\mathbf{W_{10m}}$ to predict leeway speed, **CWL**, and **DWL**.

In cases for which the mean of the leeway speed is as good (or better) than the linear model using $\mathbf{W_{10m}}$ as a predictor we will still present the linear model using $\mathbf{W_{10m}}$ because historical evidence is very strong that leeway is a function of wind speed.

Prediction limits were used to estimate (with 95% confidence) the upper and lower limits for the next individual outcome (the leeway speed or component) at an estimated wind speed (Equation 3.3). A second-order polynomial equation was then fitted to each limit over the wind speed range.

$$95\%\ \text{Prediction limit} \cong c_1*(\mathbf{W_{10m}})^2 + c_2*(\mathbf{W_{10m}}) + c_3 \qquad (3-3)$$

where:

c_1 has units of $cm*s*m^{-2}$,
c_2 has units of $cm*m^{-1}$, and
c_3 has units of $cm*s^{-1}$

The coefficients of the second order polynomials that describe the 95% prediction limits for the regressions are presented for five leeway target types in tables in Chapter 4. For a complete description of the statistical techniques used, see Allen (1996).

3-2.3 Piece-wise Regression Rules

The crosswind component of leeway versus wind speed is a bi-modal data set, which necessitates a piece-wise scheme for regression analysis purposes. There are a number of legitimate methods for separating the data set into subclasses before applying the regression and after recombining the regressions. The following rules provided the guidance used for piece-wise regressions in this report.

1) All legitimate data pairs shall be used. (All data that was valid was used).

2) Use the data pairs only once. (All good data pairs had a weighting of one.)

3) Make data set breaks along natural boundaries. (Divisions were not random.)

4) Recombine regressions to provide a model that includes most of the original data pairs and excludes regions without data pairs. (Prediction limits encompassed the data and avoided large regions where no observations occurred).

5) The combined regressions are to be mathematically implemented. (Discontinuities and ambiguities were avoided in the model to provide smooth transitions with minimum decision rules.)

3-2.4 Reference Levels and Units Used

The definition of leeway used for this work was presented in Section 1-2. The analysis of the SAR object leeway is presented relative to the water at 0.70 m depth (or as stated). The leeway is expressed in terms of wind velocity corrected for each platform's motion, adjusted to a reference height of 10 meters.

The units used in this report are meters (m) for height and depth. Speeds are reported in meters per second (m/s) for wind speed, centimeters per second (cm/s) for leeway speed and the leeway components. Angular measurements are in degrees. Degrees Celsius are used for air and water temperatures. Time is reported in the Universal Time Coordinate (UTC) hour of the day. Local time was UTC+5 hours.

3-3 SUMMARY OF DATA RECOVERY

Table 3-2 lists the leeway data that were recovered during the January/February 1998 field experiment and used in the analysis.

Table 3-2. Summary of Data Recovered Delaware Offshore, January/February 1998

Leeway Craft	Leeway Run	Wind Data Source	Leeway Data	Data Total (hh:mm)	Comments
PIW - I	121 & 126	WeatherPak® @ Wharf Box	Aanderaa IDCS	23:30	
PIW - SS	119, 122, 125, & 129	WeatherPak® @ Wharf Box	Aanderaa IDCS	59:06	IDCS malfunctioned on run #129
Windsurfer	115, 118, & 123	WeatherPak® @ Wharf Box	SonTek ADCM	61:18 53:30 used	Capsized on run #115
Sea Kayak	113, 116, & 120	WeatherPak® @ Wharf Box	Aanderaa IDCS	65:00 57:12 used	
Wharf Box (light)	114 & 117	WeatherPak®	S4 EMCM	52:18	EMCM stopped early on run #114
Wharf Box (heavy)	127&128	WeatherPak®	S4 EMCM	49:18	

3-4 SUMMARY OF DATA REDUCTION

The raw leeway data sets were edited to include only those sampling intervals when the craft was free-drifting and clear of interference. The raw wind and leeway samples were ten minute vector averages. The basic procedures followed Fitzgerald et al. (1993), Fitzgerald et al. (1994) and Allen (1996). Time is expressed in UTC at the center of each 10 minute sample.

The wind data from the MiniMet® buoy were used for this experiment (see Section 2-5). Raw Wind data were rotated from magnetic to true coordinates, and then rotated 180 degrees to convert from the meteorological to the oceanographic convention. The MiniMet's® anemometer had a clean airflow, with minimum buoy motion. The total wind direction error based on the calibration of the MiniMet's® anemometer and compass was estimated to have been plus or minus 2 degrees. Wind speed was adjusted from the anemometer level (3.0 m) to the 10 m reference height using the algorithm described by Smith (1988). The wind vectors adjusted to the 10 m reference height are referred to in this report as $\mathbf{W_{10m}}$.

The use of MiniMet® buoy wind data during the Fort Pierce, FL test produced some results that were clearly in error. These problems were addressed for the Delaware test. As a result the WeatherPak® onboard the Wharf Box was used for wind data. Wind direction data were corrected by using the more stable wind direction of the MiniMet® buoy when the WeatherPak® and MiniMet® were separated by 15 km or less. This criterion, in fact, was never exceeded. The distances of the leeway craft from the WeatherPak® during the Delaware test are summarized in Table 3-3.

Table 3-3. Distance of the Leeway Craft from the WeatherPak® Buoy Delaware Offshore, January/February 1998

Leeway Craft	Leeway Run #	Distance from WeatherPak®	
		Min	Max
PIW–I	121 & 126	0.1-km	5.4-km
PIW–SS	119, 122, 125	0.1-km	12.4-km
Windsurfer	115 & 118	0.1-km	8.6-km
Sea Kayak	113 & 116	0.1-km	4.7-km
Wharf Box–light	114 & 117	0.0-km	0.0-km
Wharf Box–heavy	127 & 128	0.0-km	0.0-km

The 10 minute averages from the S4® EMCMs were used for leeway and were edited by removing the portions of records before and after the leeway runs. The records were rotated to convert from magnetic north to true north. The velocities were rotated 180 degrees to convert the relative motion of the water past the current meter to true motion of craft through the water. The leeway records were synchronized with the wind records and combined together into arrays.

The GPS position records used to track the drift of the craft were also edited to remove the portions before and after the actual drift. The number of positions includes both the positioning of the craft by the work vessel upon deployment and by the onboard GPS.

Leeway data were matched, based on time, with the corresponding wind data. Leeway angle and the downwind and crosswind components of leeway were calculated by using the 10-minute, vector-averaged wind direction from the MiniMet® buoy. Leeway rate was calculated using $\mathbf{W_{10m}}$ from the MiniMet® buoy.

3-5 SUMMARY OF THE DATA SET

Table 3-4 provides a summary by drift run of the data sets (Appendix A) collected during the 1998 field work. Wave height is significant wave height measured by the MiniMet® buoy.

Table 3-4. **Summary of Leeway Drift Runs Delaware Offshore, January/February 1998**

Craft	Leeway Run #	Data (hh:mm)	W_{10m} Range (m/s)	W_{10m} Mean (m/s)	H_s Wave Height Range (m)	H_s Mean (m)
PIW-I	121	7:48	2.1 - 4.7	3.5	0.7 – 0.9	0.8
PIW-I	126	15:48	4.6 - 12.2	8.4	1.9 – 2.6	2.2
PIW-SS	119	35:30	2.0 - 10.5	5.0	1.3 – 2.7	1.8
PIW-SS	122	7:48	2.1 - 4.7	3.5	0.7 – 0.9	0.8
PIW-SS	125	15:48	4.6 - 12.2	8.4	1.9 – 2.6	2.2
Windsurfer	115	16:48	2.8 - 11.2	5.8	1.5 – 2.5	2.0
Windsurfer	118	35:12	2.0 - 10.5	5.0	1.3 – 2.7	1.8
Windsurfer	123	7:48	2.1 - 4.7	3.5	0.7 – 0.9	0.8
Sea Kayak	113	22:00	2.8 - 11.2	5.8	1.5 – 2.5	2.0
Sea Kayak	116	35:12	2.0 - 10.5	5.0	1.3 – 2.7	1.8
Sea Kayak	120	7:48	2.1 - 4.7	3.5	0.7 – 0.9	0.8
Wharf Box (light)	114	16:48	2.8 - 11.2	5.8	1.5 – 2.5	2.0
Wharf Box (light)	117	35:30	2.0 - 10.5	5.0	1.3 – 2.7	1.8
Wharf Box (heavy)	127	15:48	4.6 - 12.2	8.4	1.9 – 2.6	2.2
Wharf Box (heavy)	128	33:30	6.2 – 11.8	8.9	1.5 – 2.5	1.9

CHAPTER 4

RESULTS AND DISCUSSION

4-1 GENERAL

Eighteen leeway runs were conducted off the entrance of Delaware Bay from 17 January (Yearday 017) and 1 February (Yearday 032) 1998. These runs were conducted on fully instrumented drift objects of a type not evaluated in previous leeway experiments (PIW-I, PIW-SS, Windsurfer, Sea Kayak, and Wharf Box). The data collected from these eighteen runs, consecutive run #113 through run #130, constitute the basis for the analysis in this report.

The $\mathbf{W_{10m}}$ wind speed calculated from the MiniMet® data record during the test period varied between 0.1 m/s and 22.5 m/s. A record of wind speed, wind direction, and significant wave height, H_s, is presented in Figure 4-1. A record of MiniMet® air temperature, water temperature, and barometric pressure is presented in Figure 4-2.

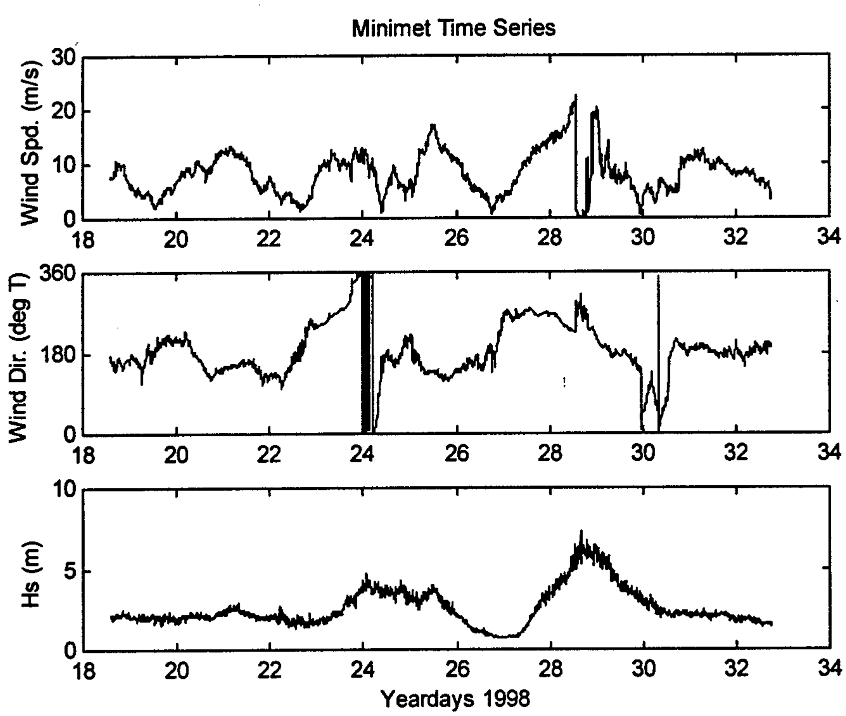


Figure 4-1. Delaware Bay Leeway Experiment MiniMet® Record of Wind Speed, Wind Direction, and Significant Wave Height

The primary source of wind speed and direction for the leeway runs off Delaware Bay was from the WeatherPak® installed on the Wharf Box. The Wharf Box was maintained within 12.4 km of the other drift objects. The secondary source of wind data was the MiniMet® meteorological buoy. The MiniMet® buoy provided a more stable platform for the collection of wind direction than the WeatherPak®. A criterion for correcting the WeatherPak® wind direction when it was more than 15 km from the MiniMet® was established based upon experience. For this experiment the criterion did not need to be applied. The MiniMet® buoy also provided a continuous record of winds in the survey area.

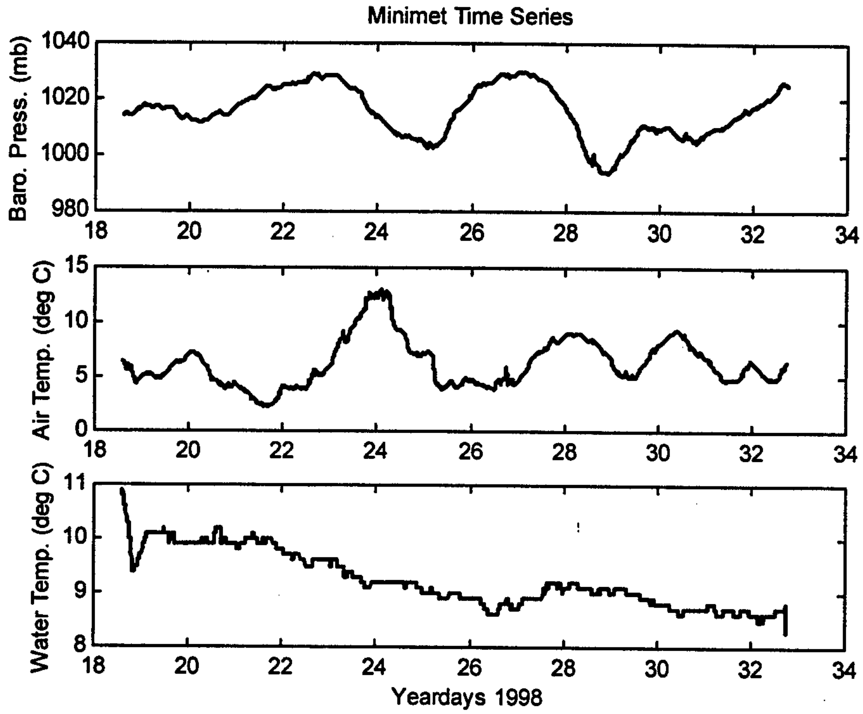


Figure 4-2. Delaware Bay Leeway Experiment MiniMet® Record of Air Temperature, Water Temperature, and Barometric Pressure

4-2 WHARF BOX

The Wharf Box, previously described in Section 2-9.4 and Figure 2-11, was included as a drift object during all of the Delaware Bay leeway runs, #113 through #130. On run #124 the S4® current meter attached to the Wharf Box did not turn on, thus eliminating that run from the Wharf Box analysis. Runs #114 and #117 were conducted with the Wharf Box configured with light loading, a one-person load. Runs #127 and #128 were configured with heavy loading, a four-person load.

4-2.1 Wharf Box Leeway, One-person Loading

The Wharf Box when configured for the weight of one person was deployed between 18/1808 January and 19/1658 January 1998 for leeway run #114 and again between 21/1805 January and 23/0616 January 1998 for leeway run #117. Total usable data from

these two runs amounted to 52 hours and 18 minutes of drift data (Table 3-4). $\mathbf{W_{10m}}$ varied between 2.0 m/s and 11.2 m/s. Wave height, H_s, varied between 1.3 m and 2.7 m (Table 3-4).

4-2.1.1 Wharf Box (one-person load) Leeway Speed and Angle

Leeway speeds as a function of $\mathbf{W_{10m}}$ for the Wharf Box (one-person) are presented in Figures 4-3 and 4-4. Figure 4-3 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 9.2 cm/s, the slope of the regression line is 2.6%, and the standard error of estimate is ±2.96 cm/s (Table 4-1). For the constrained case (Figure 4-4) the slope of the regression line is 4.1% with a standard error of estimate of ±4.85 cm/s. An r^2=0.82 for the unconstrained case indicates that 82% of the variance of leeway speed for the Wharf Box (one-person load) is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is an excellent predictor of leeway speed. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.52. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is a poorer predictor of leeway speed than in the unconstrained case.

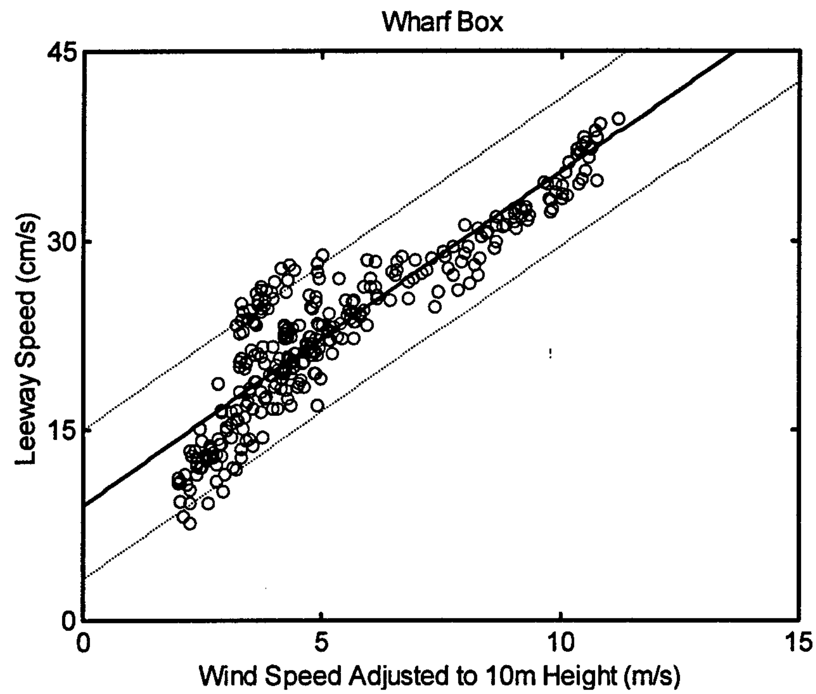


Figure 4-3. Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load

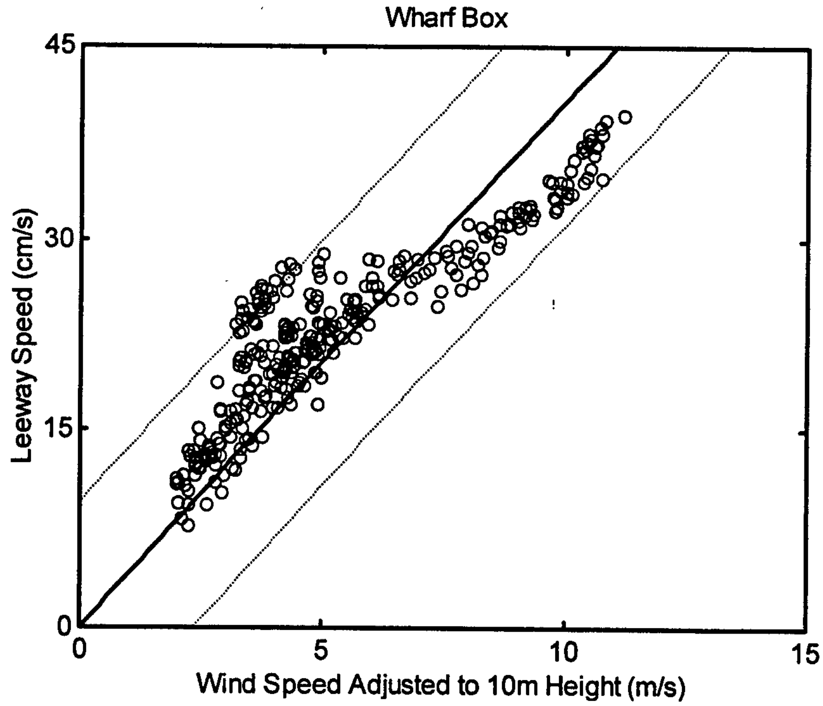


Figure 4-4. Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load

Table 4-1. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with One-person Load

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	114 & 117	316	9.16	2.63	0.82	2.96	2.0 – 11.2
Constrained	114 & 117	316	–	4.07	0.52	4.85	2.0 – 11.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-2. The 95% prediction limits are displayed in Figure 4-3 for the unconstrained case and in Figure 4-4 for the constrained case.

Table 4-2. **Coefficients of the Polynomials Describing the 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with One-person Load**

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	2.611	15.052	-0.002	2.644	-3.285
Constrained	0.000	4.074	9.546	0.000	4.074	-9.546

The leeway angle of drift with respect to the downwind direction was slightly to the right of the downwind direction above a $\mathbf{W_{10m}}$ wind speed of 5 m/s (Figure 4-5). The greatest leeway angle to the right of the downwind direction was 37°. The greatest leeway angle to the left of downwind was 29° for all wind speeds. For winds greater than 5 m/s it was 2° (Table 4-3). The mean leeway angle was 5° to the right of the downwind direction for all wind speeds and 11° to the right of the wind for winds greater than 5 m/s. The standard deviation of the leeway angle was ±13° for all winds and ±9° for winds greater than 5 m/s. Examining only absolute values of the leeway angle gives a mean angle of

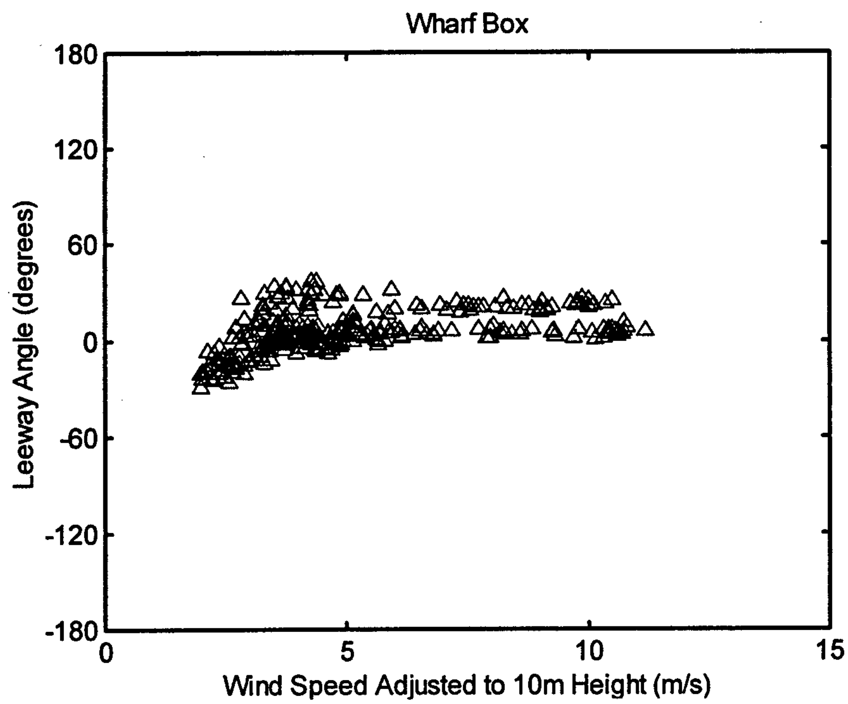


Figure 4-5. **Leeway Angle (degrees) vs.10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load**

10° with a standard deviation of ±9° for all winds and a mean of 11° with a standard deviation of ±8° for winds greater than 5 m/s. These leeway angle data show a steady preference for a drift slightly to the right of the wind for the Wharf Box lightly loaded.

Table 4-3. Leeway Angle (degrees): Wharf Box Configured with One-person Load

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle				Abs. Angle	
			mean	s.dev.	min	max	mean	s.dev.
All Winds	316	2.0 – 11.2	5	13	-29	37	10	9
Winds > 5 m/s	119	5.0 – 11.2	11	9	-2	37	11	8

4-2.1.2 Wharf Box (one-person) - Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the Wharf Box (one-person load) is shown in Figures 4-6 and 4-7. The unconstrained (Figure 4-6) and the constrained (Figure 4-7) linear regressions along with the 95% prediction limits are shown for leeway runs #114 and #117. Table 4-4 summarizes the regressions for the unconstrained and constrained cases for **DWL,** and Table 4-5 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-6) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 9.0 cm/s, the slope of the regression line is 2.5%, and the standard error of estimate is ±3.05 cm/s (Table 4-4). For the constrained case (Figure 4-7) the slope of the regression line is 3.9% with a standard error of estimate of ±4.85 cm/s. An r^2=0.80 for the unconstrained case indicates that 80% of the variance of **DWL** for the Wharf Box (one-person load) is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is an excellent predictor of **DWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.50. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is only a fair predictor of **DWL**.

Table 4-4. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with One-person Load

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	114 & 117	316	9.01	2.53	0.80	3.05	2.0 – 11.2
Constrained	114 & 117	316	–	3.95	0.50	4.85	2.0 – 11.2

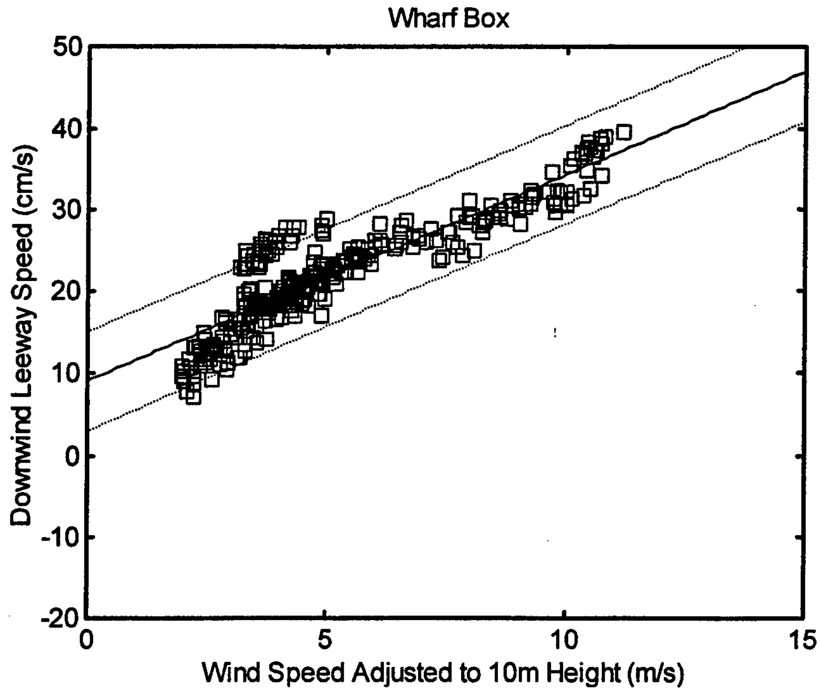


Figure 4-6. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load

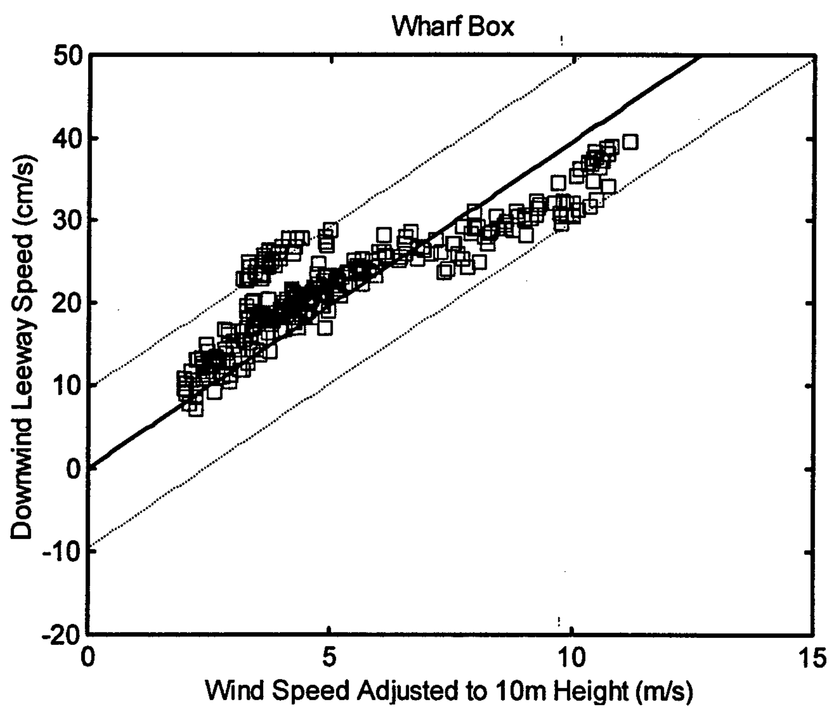


Figure 4-7. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-5. The curves are displayed on Figure 4-6 for the unconstrained case and on Figure 4-7 for the constrained case.

Table 4-5. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with One-person Load

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	2.514	15.065	-0.002	2.548	2.953
Constrained	0.000	3.952	9.549	0.000	3.952	-9.549

The crosswind component of leeway (**CWL**) as a function of $\mathbf{W_{10m}}$ for the Wharf Box (one-person load) is shown in Figures 4-8 and 4-9. For leeway runs #114 and #117 the heavy majority of the **CWL** values were positive and there was not a period during the tests when the **CWL** was persistently negative. Therefore the data for the two runs were combined for analysis of **CWL**. The unconstrained (Figure 4-8) and the constrained (Figure 4-9) linear regression along with the 95% prediction limits are shown for leeway runs #114 and #117. Table 4-6 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-7 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-8) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}=0$ is –2.8 cm/s, the slope of the regression line is 1.1%, and the standard error of estimate is ±4.14 cm/s (Table 4-6). For the constrained case (Figure 4-9) the slope of the regression line is 0.6% with a standard error of estimate of ±4.29 cm/s. An $r^2=0.29$ for the unconstrained case indicates that 29% of the variance of **CWL** for the Wharf Box (one-person load) is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is a poor predictor of **CWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.23. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is as poor a predictor of **CWL** as in the unconstrained case.

Table 4-6. Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with One-person Load

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	114 & 117	316	-2.76	1.09	0.29	4.14	2.0 – 11.2
Constrained	114 & 117	316	–	0.65	0.23	4.29	2.0 – 11.2

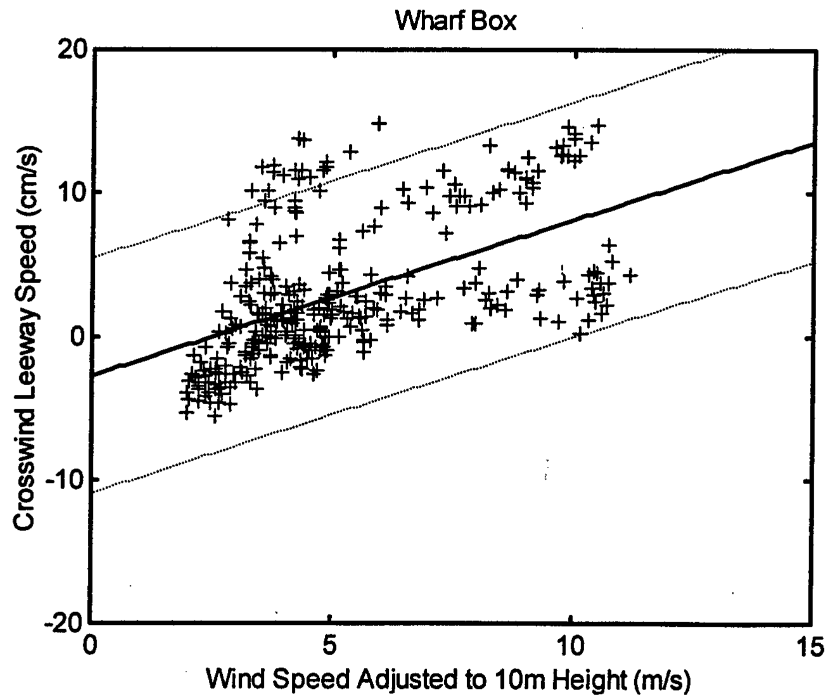


Figure 4-8. **Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load**

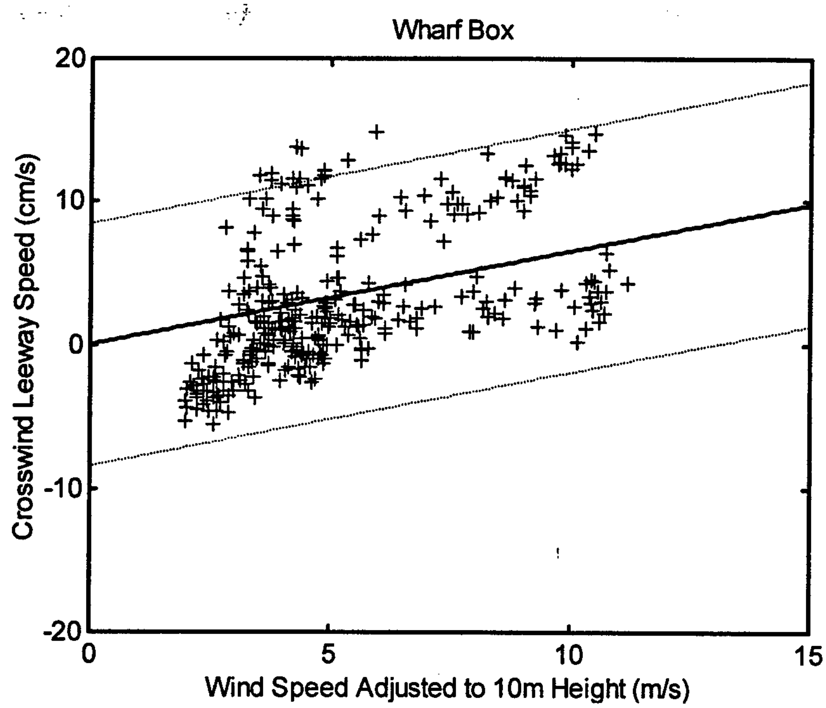


Figure 4-9. **Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with a One-person Load**

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-7. The curves are displayed on Figure 4-8 for the unconstrained case and on Figure 4-9 for the constrained case.

Table 4-7. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with One-person Load

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	1.065	5.463	-0.002	1.111	-10.979
Constrained	0.000	0.653	8.447	0.000	0.653	-8.447

4-2.2 Wharf Box Leeway, Four-person Loading

The Wharf Box when configured for the weight of four persons was deployed between 30/0855 January and 31/0121 January 1998 for leeway run #127 and again between 31/0250 January and 01/1323 February 1998 for leeway run #128. Total usable data from these two runs amounted to 49 hours and 18 minutes of drift data (Table 3-4). W_{10m} varied between 4.6 m/s and 12.2 m/s. Wave height, H_s, varied between 1.5 m and 2.6 m (Table 3-4).

4-2.2.1 Wharf Box (four-person load) Leeway Speed and Angle

Leeway speeds as a function of W_{10m} for the Wharf Box (four-person load) are presented in Figures 4-10 and 4-11. Figure 4-10 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or leeway speed at W_{10m}=0 is 8.0 cm/s, the slope of the regression line is 1.6%, and the standard error of estimate is ±2.70 cm/s (Table 4-8). For the constrained case (Figure 4-11) the slope of the regression line is 2.5% with a standard error of estimate of ±3.03 cm/s. An r^2=0.46 for the unconstrained case indicates that 46% of the variance of leeway speed for the Wharf Box (four-person load) is explained by using W_{10m} as a predictor. This value of r^2 indicates that W_{10m} is a fair predictor of leeway speed.

Table 4-8. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with Four-person Load

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	127 & 128	297	7.99	1.63	0.46	2.70	4.6 – 12.2
Constrained	127 & 128	297	–	2.52	0.33	3.03	4.6 – 12.2

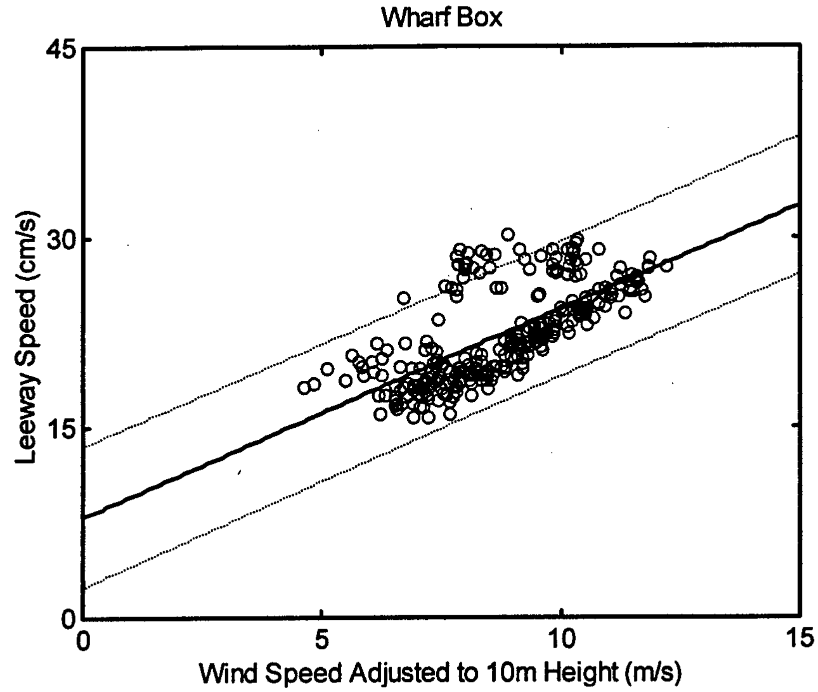


Figure 4-10. **Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load**

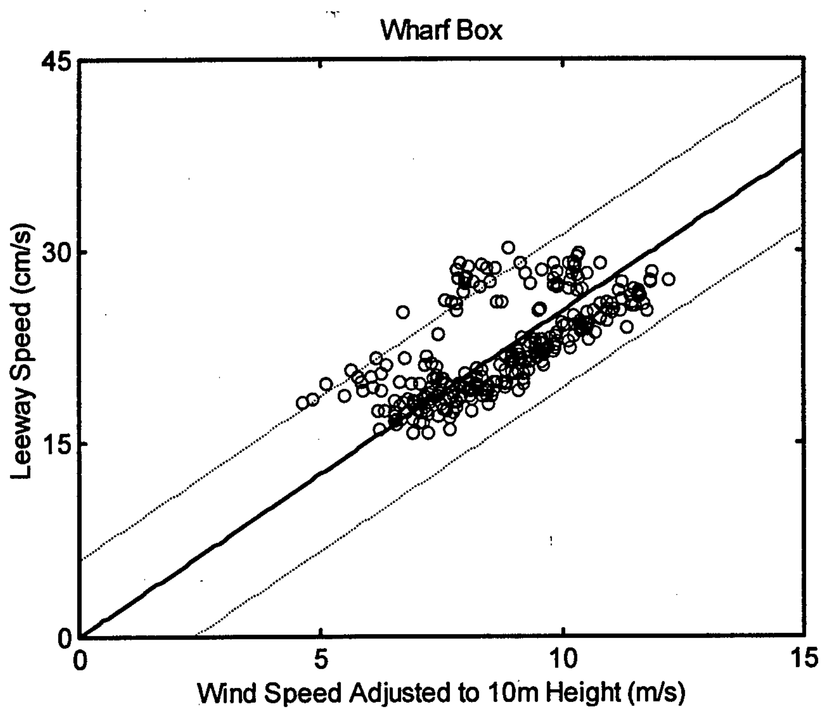


Figure 4-11. **Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load**

The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.33. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is a poor predictor of leeway speed.

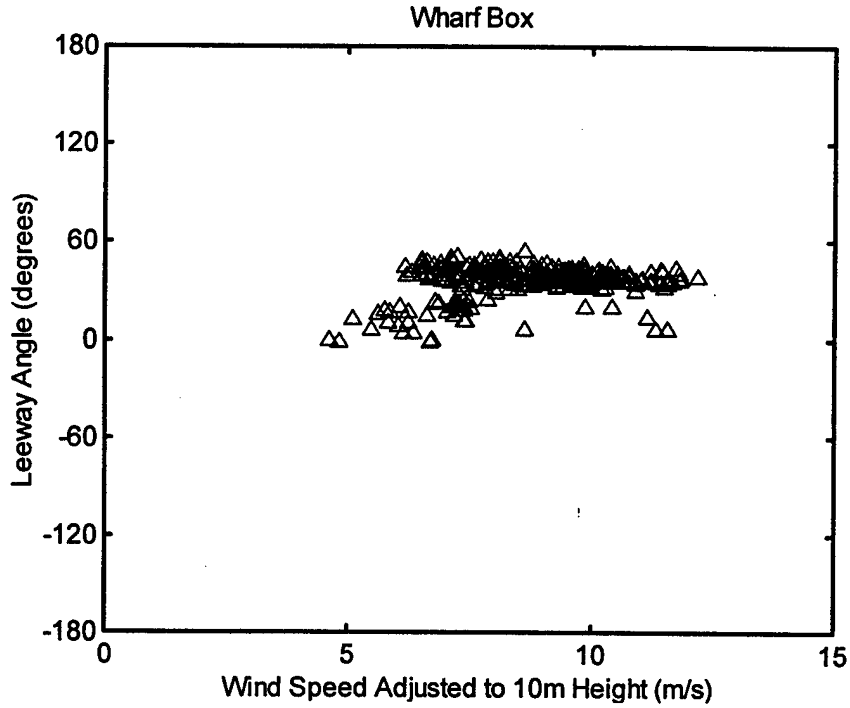


Figure 4-12. Leeway Angle (degrees vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-9. The curves are displayed on Figure 4-10 for the unconstrained case and on Figure 4-11 for the constrained case.

Table 4-9. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with Four-person Load

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.004	1.570	13.578	-0.004	1.697	2.396
Constrained	0.000	2.523	5.968	0.000	2.523	-5.968

The leeway angle of drift with respect to the downwind direction was well to the right of the downwind direction. Only two samples of $\mathbf{W_{10m}}$ were less than 5 m/s and those two samples were higher than 4.6 m/s (Figure 4-12). Lower wind speeds were entirely lacking. The greatest leeway angle to the left of downwind was 2° for wind speeds greater

than 5 m/s (Table 4-10). The greatest leeway angle to the right of the downwind direction was 54° for wind speeds greater than 5 m/s. The mean leeway angle was 35° to the right of the downwind direction for winds greater than 5 m/s. The standard deviation of the leeway angle was ±9° for winds greater than 5 m/s. The mean and standard deviation of the absolute values of the leeway angle were identical to those stated above since all but a few values were to the right of the wind direction for winds greater than 5 m/s. These leeway angle data show a steady preference for a drift to the right of the wind for the Wharf Box heavily loaded.

Table 4-10. Leeway Angle (degrees): Wharf Box Configured with Four-person Load

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle mean	s.dev.	min	max	Abs. Angle mean	s.dev.
Winds > 5 m/s	295	5.0 – 12.2	35	9	-2	54	35	9

4-2.2.2 Wharf Box (four-person load) - Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the Wharf Box (four-person load) is shown in Figures 4-13 and 4-14. The unconstrained (Figure 4-13) and the constrained (Figure 4-14) linear regression along with the 95% prediction limits are shown for leeway runs #127 and #128. Table 4-11 summarizes the regressions for the unconstrained and constrained cases for **DWL** and Table 4-12 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-13) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 7.9 cm/s, the slope of the regression line is 1.1%, and the standard error of estimate is ±3.17 cm/s (Table 4-11). For the constrained case (Figure 4-14) the slope of the regression line is 2.0% with a standard error of estimate of ±3.45 cm/s. An r^2=0.24 for the unconstrained case indicates that 24% of the variance of **DWL** for the Wharf Box (four-person load) is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is a poor predictor of **DWL**. The value of r^2 for the case where the

Table 4-11. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with Four-person Load

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	127 & 128	297	7.94	1.15	0.24	3.17	4.6 – 12.2
Constrained	127 & 128	297	–	2.03	0.09	3.45	4.6 – 12.2

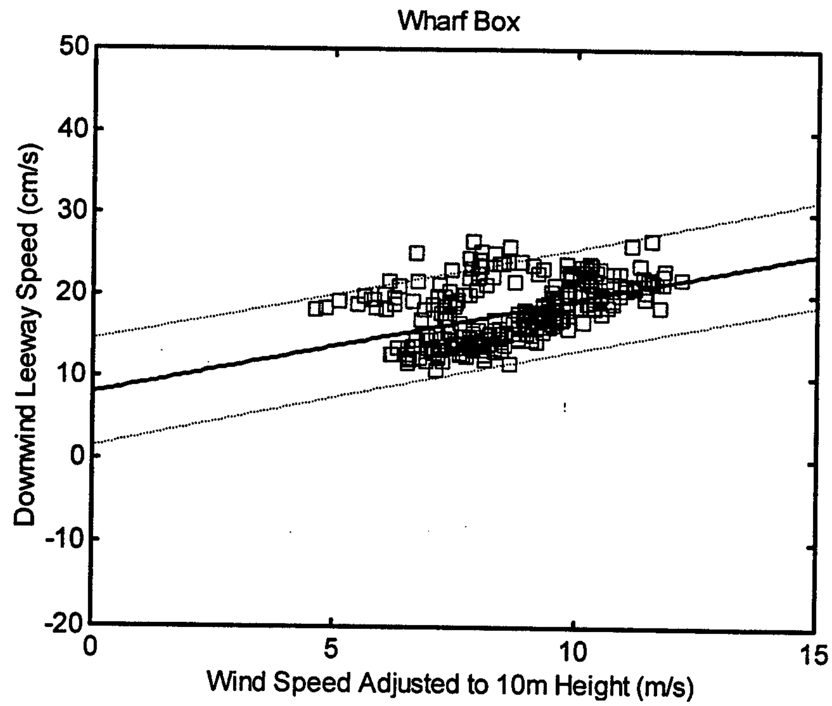


Figure 4-13. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load

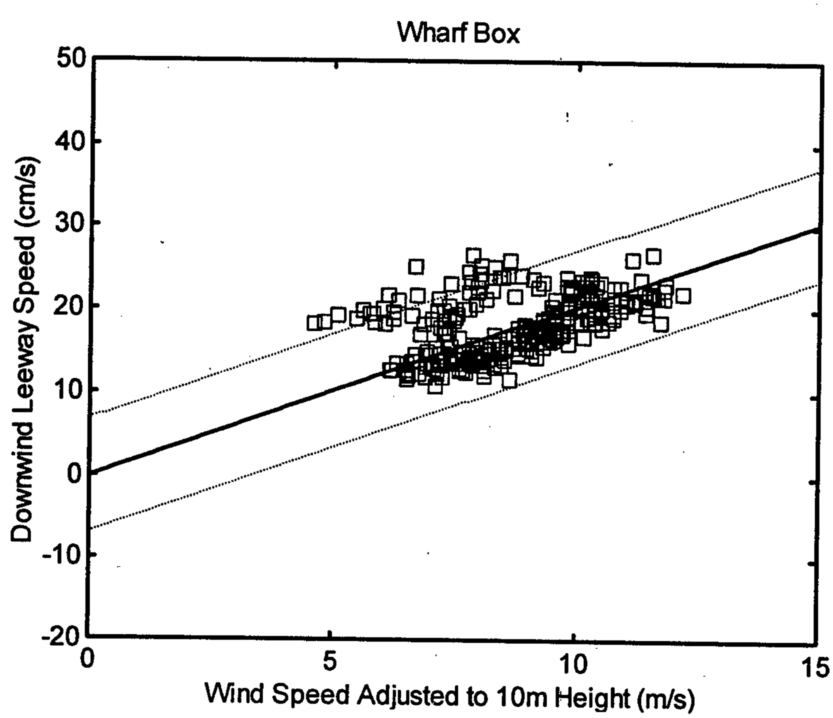


Figure 4-14. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load

regression line is constrained to pass through the origin is 0.09. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is not much better than the mean of **DWL** as a predictor of **DWL**.

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-12. The curves are displayed on Figure 4-13 for the unconstrained case and on Figure 4-14 for the constrained case.

Table 4-12. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with Four-person Load

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.004	1.074	14.503	-0.004	1.223	1.370
Constrained	0.000	2.032	6.794	0.000	2.032	-6.794

The crosswind component of leeway (**CWL**) as a function of $\mathbf{W_{10m}}$ for the Wharf Box (four-person load) is shown in Figures 4-15 and 4-16. For leeway runs #127 and #128 the heavy majority of the **CWL** values were positive and there was not a period during the tests when the **CWL** was persistently negative. Therefore the data for the two runs were combined for analysis of **CWL**. The unconstrained (Figure 4-15) and the constrained (Figure 4-16) linear regression along with the 95% prediction limits are shown for leeway runs #127 and #128. Table 4-13 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-14 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-15) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is –0.3 cm/s, the slope of the regression line is 1.5%, and a standard error of estimate of ±2.99 cm/s (Table 4-13). For the constrained case (Figure 4-16) the slope of the regression line is 1.4% with a standard error of estimate of ±2.99 cm/s. An r^2=0.37 for the unconstrained case indicates that 37% of the variance of **CWL** for the Wharf Box (four-person load) is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is a poor predictor of **CWL**. The value of r^2 for the case where the regression line is

Table 4-13. Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with Four-person Load

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	127 & 128	297	-0.32	1.48	0.37	2.99	4.6 – 12.2
Constrained	127 & 128	297	–	1.44	0.37	2.99	4.6 – 12.2

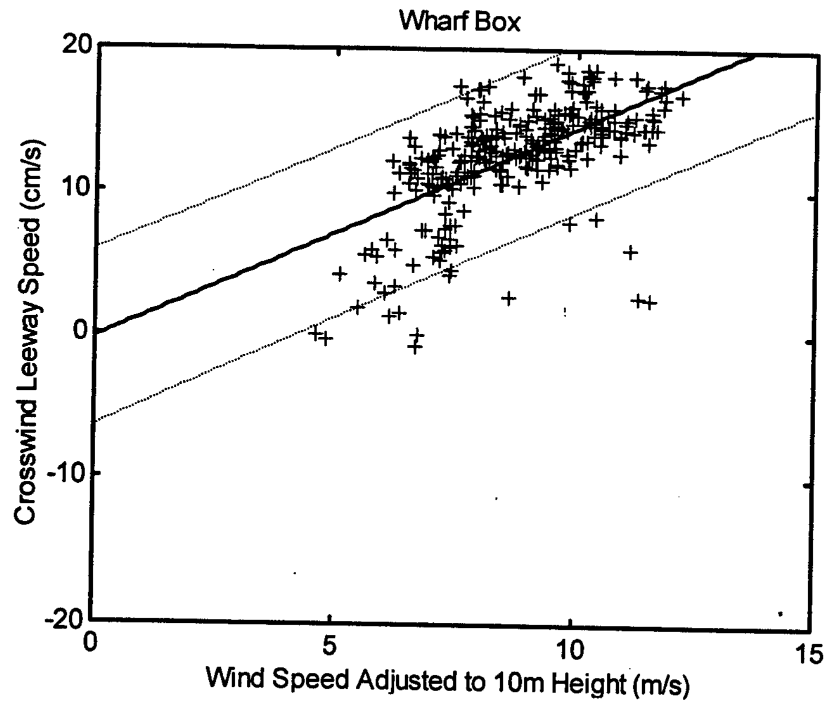


Figure 4-15. Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load

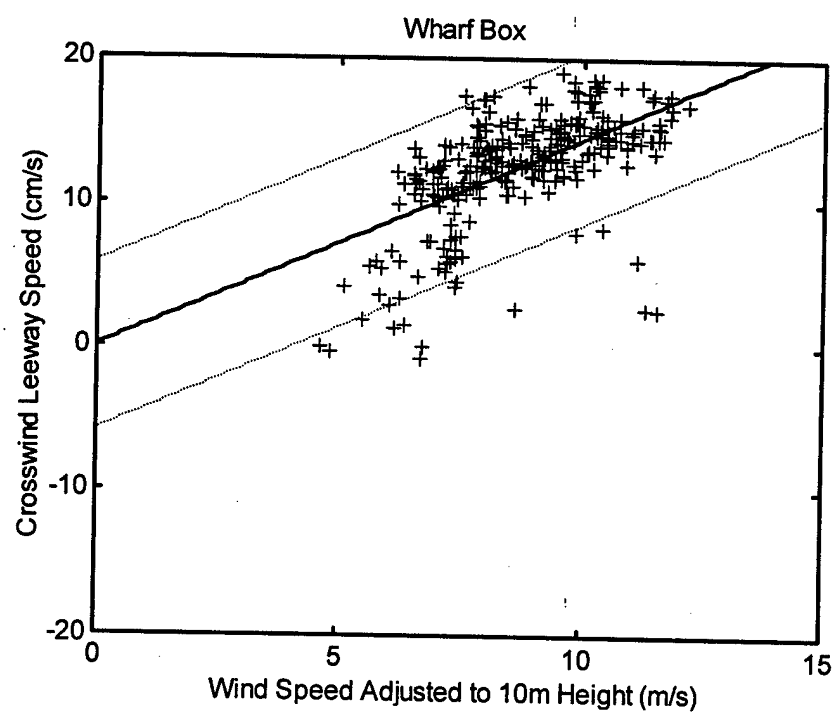


Figure 4-16. Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box Configured with Four-person Load

constrained to pass through the origin is also 0.37. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is as good predictor of **CWL** since the value of the y-axis intercept in the unconstrained case is quite small.

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-14. The curves are displayed on Figure 4-15 for the unconstrained case and on Figure 4-16 for the constrained case.

Table 4-14. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box Configured with Four-person Load

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.004	1.410	5.888	-0.004	1.551	-6.525
Constrained	0.000	1.445	5.880	0.000	1.445	-5.880

4-2.3 Wharf Box Leeway, All Data

The data from sections 4-2.1 and 4-2.2 were combined fo: an analysis of the leeway characteristics of the Wharf Box without regard to loading. The Wharf Box was deployed between 18/1808 January and 19/1658 January 1998 for leeway run #114, between 21/1805 January and 23/0616 January 1998 for leeway run #117, between 30/0855 January and 31/0121 January 1998 for leeway run #127, and again between 31/0250 January and 01/1323 February 1998 for leeway run #128. Total usable data from these four runs amounted to 101 hours and 36 minutes of drift data (Table 3-4). $\mathbf{W_{10m}}$ varied between 2.0 m/s and 12.2 m/s. Wave height, H_s, varied between 1.3 m and 2.7 m (Table 3-4).

4-2.3.1 Wharf Box (all data) Leeway Speed and Angle

Leeway speeds as a function of $\mathbf{W_{10m}}$ for the Wharf Box (all data) are presented in Figures 4-17 and 4-18. Figure 4-17 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 13.8 cm/s, the slope of the regression line is 1.3%, and the standard error of estimate is ±4.50 cm/s (Table 4-15). For the constrained case (Figure 4-18) the slope of the regression line is 3.0% with a standard error of estimate of ±6.70 cm/s. An r^2=0.37 for the unconstrained case indicates that 37% of the variance of leeway speed for the Wharf Box (all data) is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is a poor predictor of leeway speed. The

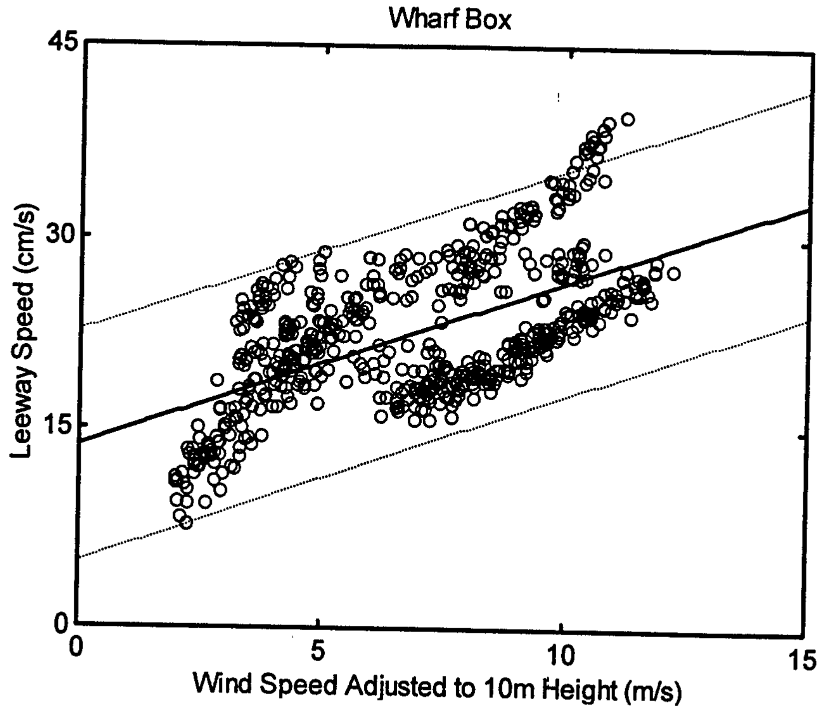


Figure 4-17. Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

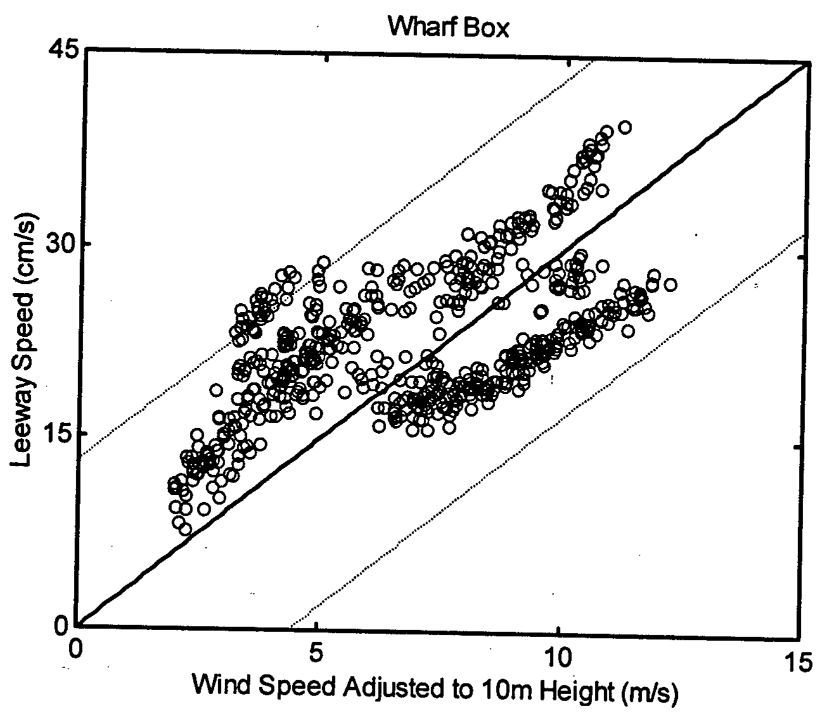


Figure 4-18. Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

value of r^2 for the case where the regression line is constrained to pass through the origin is –0.41. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case **W_{10m}** is a worse predictor of the leeway speed than is a simple mean of the leeway speed.

Table 4-15. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Wharf Box with One and Four-person Loads

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	114, 117, 127, & 128	613	13.75	1.28	0.37	4.50	2.0 – 12.2
Constrained	114, 117, 127, & 128	613	–	3.00	-0.41	6.70	2.0 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-16. The curves are displayed on Figure 4-17 for the unconstrained case and on Figure 4-18 for the constrained case.

Table 4-16. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Wharf Box with One and Four-person Loads

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.001	1.262	22.644	-0.001	1.290	4.856
Constrained	0.000	3.005	13.168	0.000	3.005	-13.168

With few exceptions for winds greater than 5 m/s the leeway angle of drift with respect to the downwind direction was consistently to the right of the downwind direction. Except for two data points all of the data for winds under 5 m/s was for the Wharf Box loaded

Table 4-17. Leeway Angle (degrees): Wharf Box with One and Four-person Loads

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle				Abs. Angle	
			mean	s.dev.	min	max	mean	s.dev.
All Winds	613	2.0 – 12.2	20	19	-29	54	22	15
Winds > 5 m/s	414	5.0 – 12.2	28	14	-2	54	28	14

with a one-person load (Figure 4-19). Lower wind speeds were entirely lacking for the Wharf Box load with a four-person load. The greatest leeway angle to the left of downwind was 29° for all wind speeds and 2° for winds greater than 5 m/s (Table 4-17).

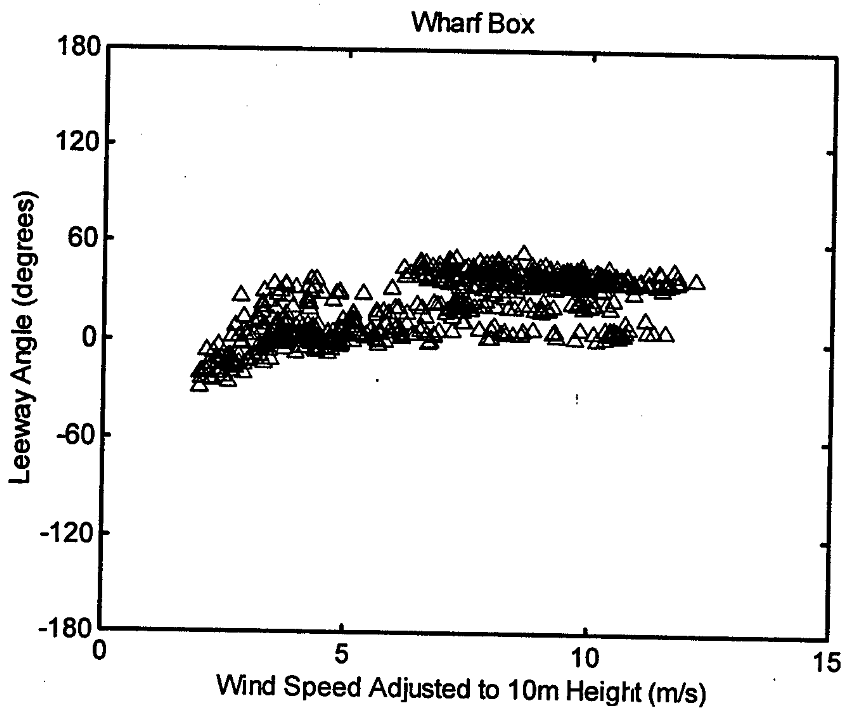


Figure 4-19. Leeway Angle (degrees vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

The greatest leeway angle was 54° to the right of the downwind direction for all wind speeds and also 54° for winds greater than 5 m/s. The mean leeway angle was 20° to the right for all winds and 28° to the right for wind speeds greater than 5 m/s. The standard deviation of the leeway angle was ±19° for all winds and ±14° for winds greater than 5 m/s. The mean of the absolute values of the leeway angle was 22° for all wind speeds and 28° for $\mathbf{W_{10m}}$ winds greater than 5 m/s. The standard deviations of the absolute values of the leeway angle were ±15° and ±14° respectively for all wind speeds and wind speeds greater than 5 m/s. The leeway angle is greater to the right as the wind speed increases and the loading of the Wharf Box increases. At the higher wind speeds the leeway angle fell roughly in the band of 0° to 50° to the right of the wind.

4-2.3.2 Wharf Box (all data) - Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the Wharf Box (all data) is shown in Figures 4-20 and 4-21. The unconstrained (Figure 4-20) and the constrained (Figure 4-21) linear regressions along with the 95% prediction limits are shown for leeway runs #114, #117, #127, and #128. Table 4-18 summarizes the

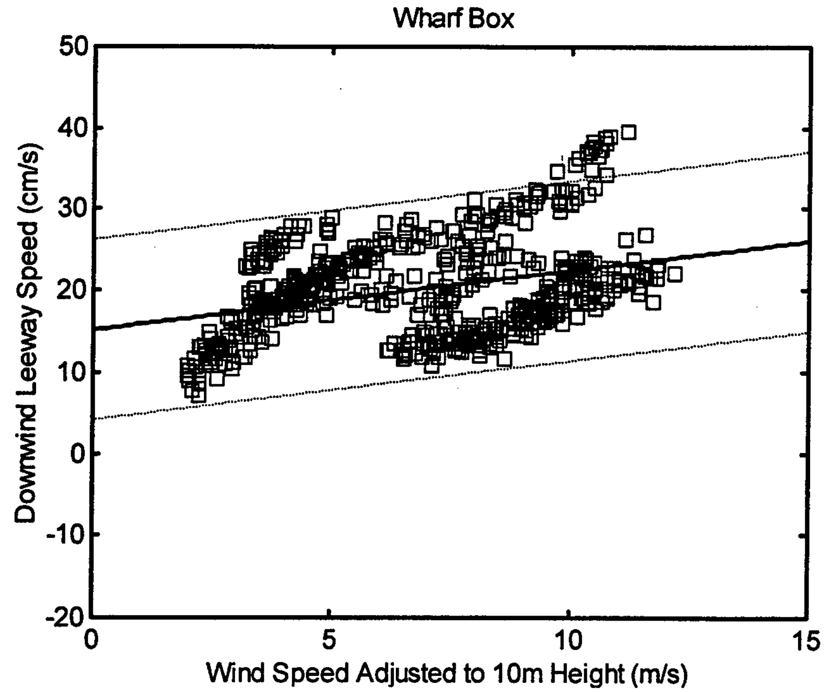


Figure 4-20. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

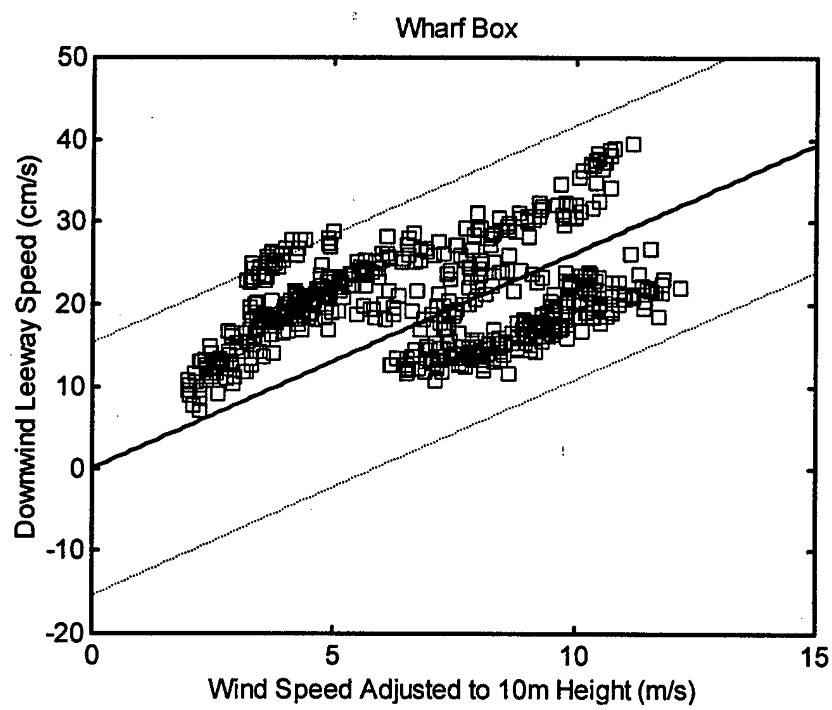


Figure 4-21. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

regressions for the unconstrained and constrained cases for **DWL** and Table 4-19 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-20) the y-axis intercept or leeway speed at W_{10m}=0 is 15.2 cm/s, the slope of the regression line is 0.7%, and the standard error of estimate is ±5.59 cm/s (Table 4-18). For the constrained case (Figure 4-21) the slope of the regression line is 2.6% with a standard error of estimate of ±7.83 cm/s. An r^2=0.11 for the unconstrained case indicates that 11% of the variance of **DWL** for the Wharf Box (all data) is explained by using W_{10m} as a predictor. Such a low value of r^2 indicates that W_{10m} is a very poor predictor of **DWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is –0.76. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case W_{10m} is a poorer predictor of **DWL** than the mean.

Table 4-18. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box with One and Four-person Loads

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	114, 117, 127, & 128	613	15.18	0.72	0.11	5.59	2.0 – 12.2
Constrained	114, 117, 127, & 128	613	–	2.63	-0.76	7.83	2.0 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-19. The curves are displayed on Figure 4-20 for the unconstrained case and on Figure 4-21 for the constrained case.

Table 4-19. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box with One and Four-person Loads

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.001	0.703	26.231	-0.001	0.737	4.125
Constrained	0.000	2.628	15.385	0.000	2.628	-15.385

The crosswind component of leeway (**CWL**) as a function of W_{10m} for the Wharf Box (all data) is shown in Figures 4-22 and 4-23. For leeway runs #114, #117, #127, and #128 the large majority of the **CWL** values were positive and there was not a period during the tests when the **CWL** was persistently negative. Therefore the data for the four runs were combined for analysis of **CWL**. The unconstrained (Figure 4-22) and the constrained

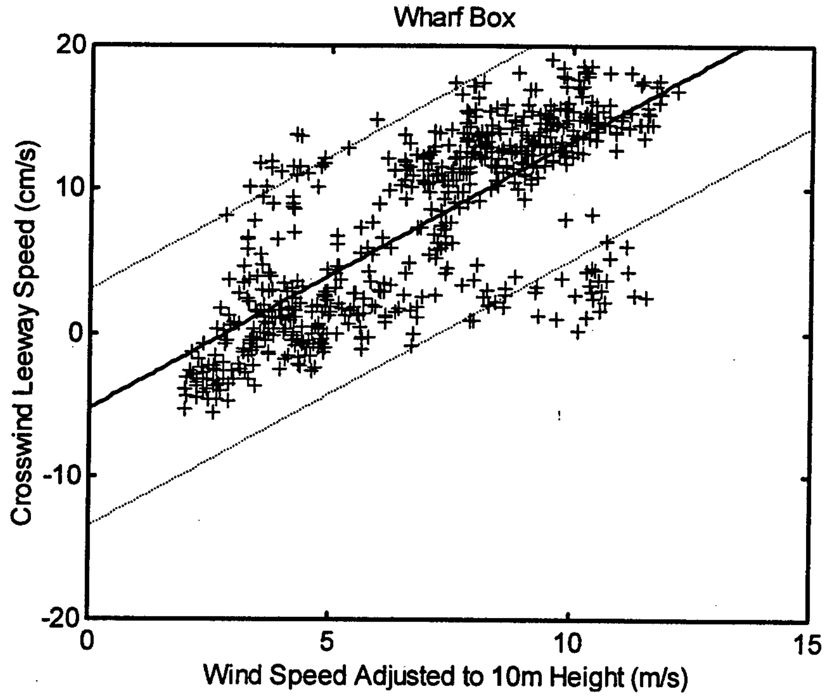


Figure 4-22. Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

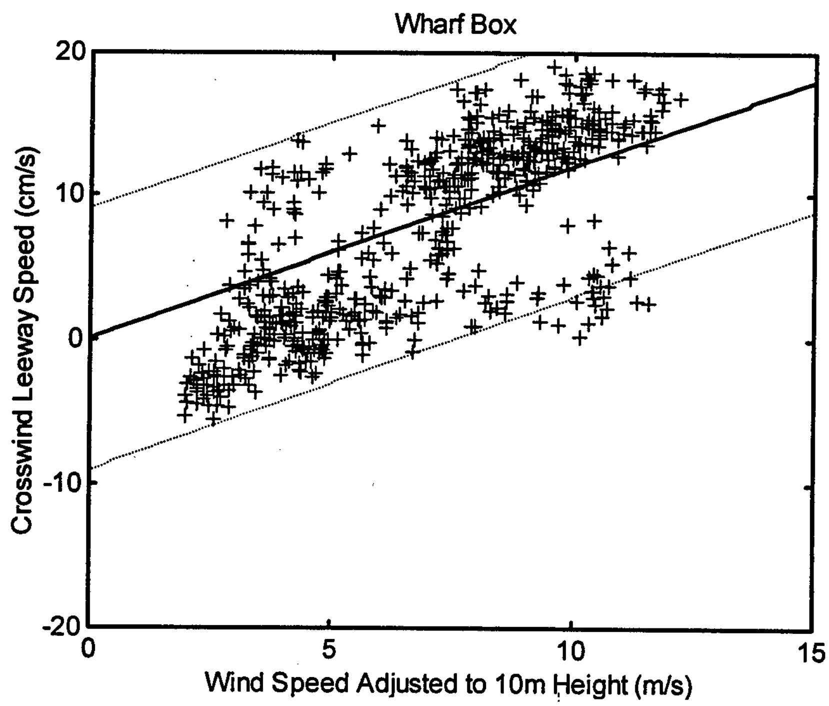


Figure 4-23. Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Wharf Box with One and Four-person Loads

(Figure 4-23) linear regression along with the 95% prediction limits are shown for leeway runs #114, #117, #127, and #128. Table 4-20 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-21 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-22) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is –5.3 cm/s, the slope of the regression line is 1.9%, and the standard error of estimate is ±4.20 cm/s (Table 4-20). For the constrained case (Figure 4-23) the slope of the regression line is 1.2% with a standard error of estimate of ±4.60 cm/s. An r^2=0.59 for the unconstrained case indicates that 59% of the variance of **CWL** for the Wharf Box (all data) is explained by using $\mathbf{W_{10m}}$ as a predictor. $\mathbf{W_{10m}}$ is fair predictor of **CWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.50. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is nearly as good a predictor of **CWL** as it is in the unconstrained case.

Table 4-20. Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box with One and Four-person Loads

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	114, 117, 127, & 128	613	-5.26	1.86	0.59	4.20	2.0 – 12.2
Constrained	114, 117, 127, & 128	613	–	1.20	0.50	4.60	2.0 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-21. The curves are displayed on Figure 4-22 for the unconstrained case and on Figure 4-23 for the constrained case.

Table 4-21. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Wharf Box with One and Four-person Loads

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.001	1.847	3.030	-0.001	1.873	-13.552
Constrained	0.000	1.199	9.041	0.000	1.199	-9.041

4-3 PERSON-IN-WATER (PIW)

Two person-in-water type leeway objects were constructed using clothing store mannequins. Both configurations were tested during the Delaware Bay leeway experiment. The first PIW configuration tested was that of a PIW in a Type I Offshore Life Jacket. This personal flotation device (PFD) provides flotation only to the upper body and as a consequence allows the person to float in an upright position with legs hanging nearly straight down in the water. The second configuration was a PIW in a survival suit. The survival suit encloses the person and provides flotation to the legs as well as the upper body. Thus the body lies flat at the surface and is exposed to wind and wave effects to a great extent. The PIW in the Type I PFD has a deeper draft and consequently has less exposure to the wind than the PIW in a survival suit.

4-3.1 Person-In-Water with Type I Personal Floatation Device (PIW-I)

The PIW-I was deployed between 26/1929 January and 27/0402 January 1998 for leeway run #121 and again between 30/0845 January and 31/0218 January 1998 for leeway run #126. Total usable data from these two runs amounted to 23 hours and 36 minutes of drift data (Table 3-4). $\mathbf{W_{10m}}$ varied between 2.1 m/s and 12.2 m/s. Wave height, H_s, varied between 0.7 m and 2.6 m (Table 3-4).

4-3.1.1 PIW-I Leeway Speed and Angle

Leeway speeds as a function of $\mathbf{W_{10m}}$ for the PIW-I are presented in Figures 4-24 and 4-25. Figure 4-24 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 0.2 cm/s, the slope of the regression line is 1.2%, and the standard error of estimate is ±1.38 cm/s (Table 4-22). For the constrained case (Figure 4-25) the slope of the regression line is 1.2% with a standard error of estimate of ±1.38 cm/s. An r^2=0.84 for the unconstrained case indicates that 84% of the variance of leeway speed for the PIW-I is reduced 84% by using $\mathbf{W_{10m}}$ as a predictor. Such a high value of r^2 indicates that $\mathbf{W_{10m}}$ is an excellent predictor of leeway speed. The value of r^2 for the case where the regression line is constrained to pass through the origin

Table 4-22. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Type I Personal Flotation Device

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	121 & 126	144	0.20	1.17	0.84	1.38	2.1 – 12.2
Constrained	121 & 126	144	–	1.19	0.84	1.38	2.1 – 12.2

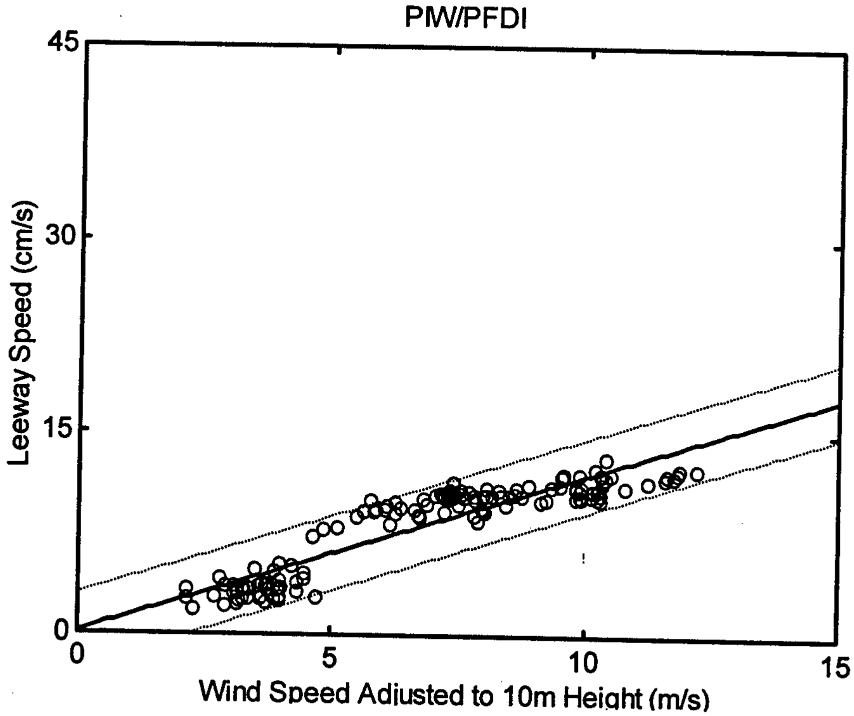


Figure 4-24. Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Type I Personal Flotation Device

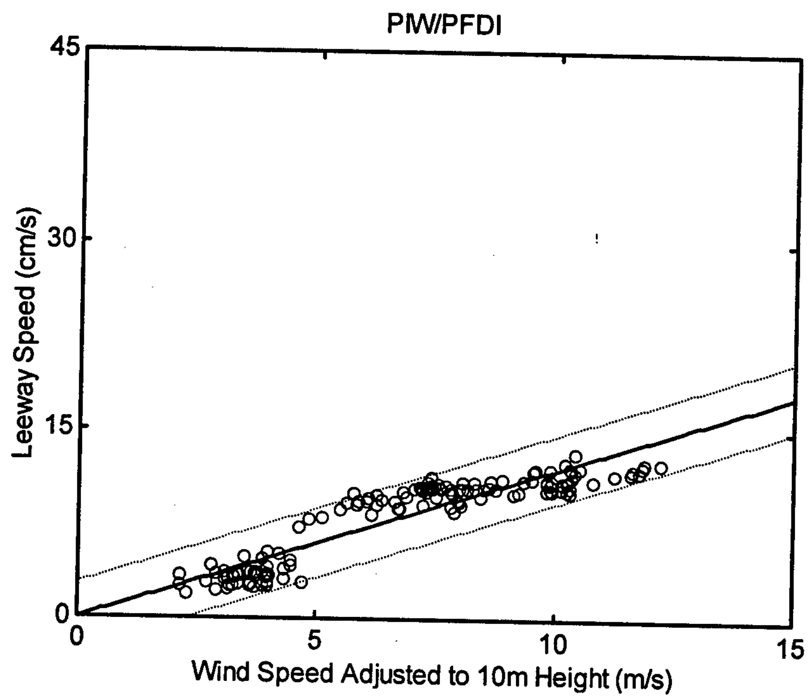


Figure 4-25. Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Type I Personal Flotation Device

is also 0.84. For the constrained case r^2 has no clear meaning (Section 3-2.2) indicates that for the constrained case $\mathbf{W_{10m}}$ is also a good predictor of leeway speed since the value of the y-axis intercept in the unconstrained case is quite small.

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-23. The curves are displayed on Figure 4-24 for the unconstrained case and on Figure 4-25 for the constrained case.

Table 4-23. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Type I Personal Flotation Device

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.001	1.151	3.003	-0.001	1.184	-2.605
Constrained	0.000	1.193	2.732	0.000	1.193	-2.732

The leeway angle of drift with respect to the downwind direction was nearly directly in the downwind direction for $\mathbf{W_{10m}}$ greater than 5 m/s. For $\mathbf{W_{10m}}$ less than 5 m/s the leeway angle was distributed through a full range of angles (Figure 4-26). The greatest leeway angle to the left of downwind was 166° for all wind speeds and 24° for winds greater than 5 m/s (Table 4-24). The greatest leeway angle to the right of the downwind direction was 176° for all wind speeds and 22° for winds greater than 5 m/s. The mean leeway angle was 20° to the right of the wind direction for all winds and 4° to the right for wind speeds greater than 5 m/s. The standard deviation of the leeway angle was ±56° for all winds and ±12° for winds greater than 5 m/s. The mean of the absolute values of the leeway angle was 38° for all wind speeds and 11° for $\mathbf{W_{10m}}$ winds greater than 5 m/s. The standard deviations of the absolute values of the leeway angle were ±45° and ±5° respectively for all wind speeds and wind speeds greater than 5 m/s. For the wind speeds greater than 5 m/s the leeway angle was small and stable in the down wind direction. This dramatic stability is likely due to the relatively deep draft of the PIW-I drift object.

Table 4-24. Leeway Angle (degrees): Person-In-Water in a Type I Personal Flotation Device

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle				Abs. Angle	
			mean	s.dev.	min	max	mean	s.dev.
All Winds	144	2.1 – 12.2	20	56	-166	176	38	45
Winds > 5 m/s	94	5.0 – 12.2	4	12	-24	22	11	5

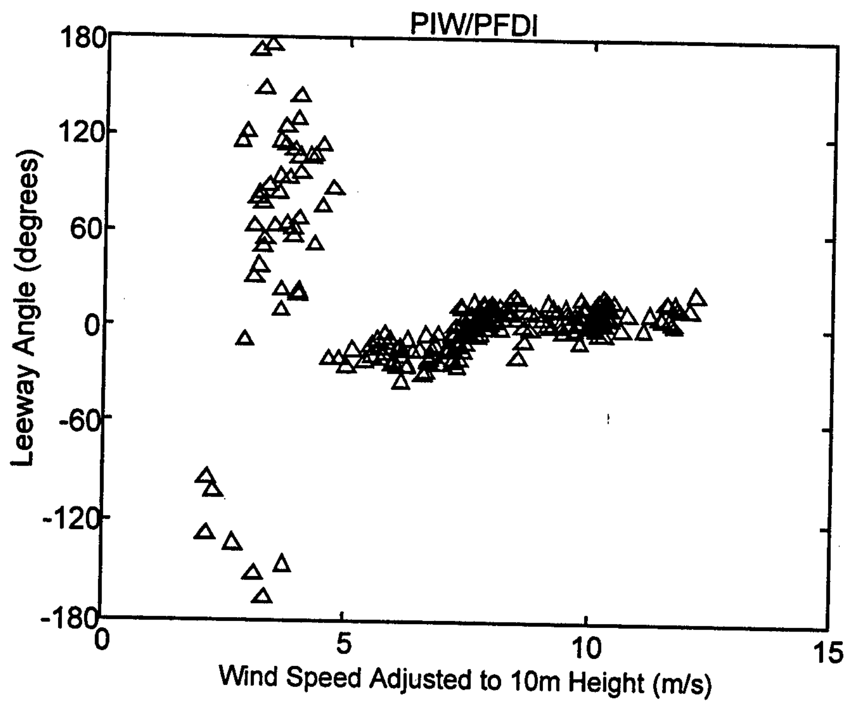


Figure 4-26. Leeway Angle (degrees) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Type I Personal Flotation Device

4-3.1.2 PIW- I Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the PIW-I is shown in Figures 4-27 and 4-28. The unconstrained (Figure 4-27) and the constrained (Figure 4-28) linear regression along with the 95% prediction limits are shown for leeway runs #121 and #126. Table 4-25 summarizes the regressions for the unconstrained and constrained cases for **DWL** and Table 4-26 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-27) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is -4.0 cm/s, the slope of the regression line is 1.6%, and the standard error of estimate is ±2.42 cm/s (Table 4-25). For the constrained case (Figure 4-28) the slope of the regression line was 1.1% with a standard error of estimate of ±2.84 cm/s. An r^2=0.77 for the unconstrained case indicates that77% of the variance of **DWL** for the PIW-I is explained by using $\mathbf{W_{10m}}$ as a predictor. This r^2 indicates that **DWL** is strongly influenced by $\mathbf{W_{10m}}$ and $\mathbf{W_{10m}}$ is a good predictor of **DWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.68. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is about as good a predictor of **DWL** as in the unconstrained case.

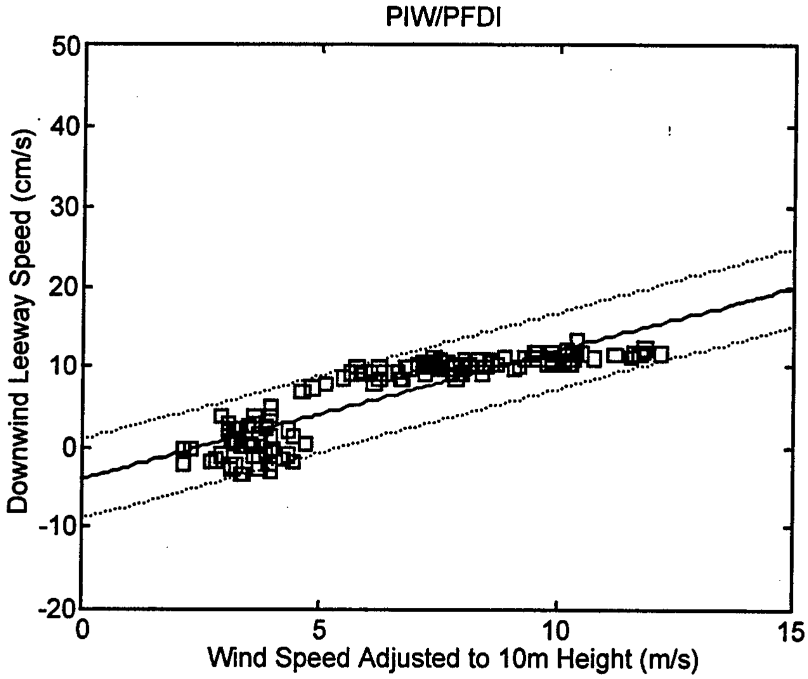


Figure 4-27. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Type I Personal Flotation Device

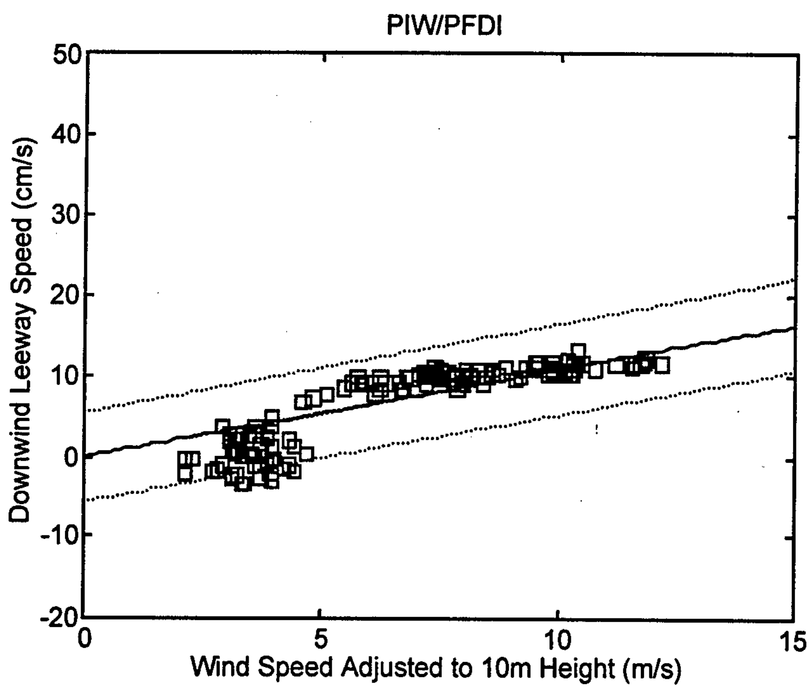


Figure 4-28. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Person-In-Water in a Type I Personal Flotation Device

Table 4-25. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Type I Personal Flotation Device

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	121 & 126	144	-3.98	1.60	0.77	2.42	2.1 – 12.2
Constrained	121 & 126	144	–	1.09	0.68	2.84	2.1 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-26. The curves are displayed on Figure 4-27 for the unconstrained case and on Figure 4-28 for the constrained case.

Table 4-26. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Type I Personal Flotation Device

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	1.570	0.913	-0.002	1.629	-8.874
Constrained	0.000	1.094	5.612	0.000	1.094	-5.612

The crosswind component of leeway (**CWL**) as a function of W_{10m} for the PIW-I is shown in Figures 4-29 and 4-30. For leeway runs #124 and #126 **CWL** values were small at all wind speeds measured. Therefore the data for the two runs were combined for analysis of **CWL**. The unconstrained (Figure 4-29) and the constrained (Figure 4-30) linear regression along with the 95% prediction limits are shown for leeway runs #124 and #126. Table 4-27 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-28 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-29) the y-axis intercept or leeway speed at $W_{10m}=0$ is 0.3 cm/s, the slope of the regression line is 0.1%, and the standard error of estimate is ±2.11 cm/s (Table 4-27). For the constrained case (Figure 4-30) the slope of the regression line is 0.2% with a standard error of estimate of ±2.11 cm/s. An $r^2=0.03$ for the unconstrained case indicates that 3% of the variance of **CWL** for the PIW-I is explained by using W_{10m} as a predictor. Such a low r^2 indicates a very small variation of **CWL** with W_{10m}. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.02. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case W_{10m} is also not a good predictor of **CWL**.

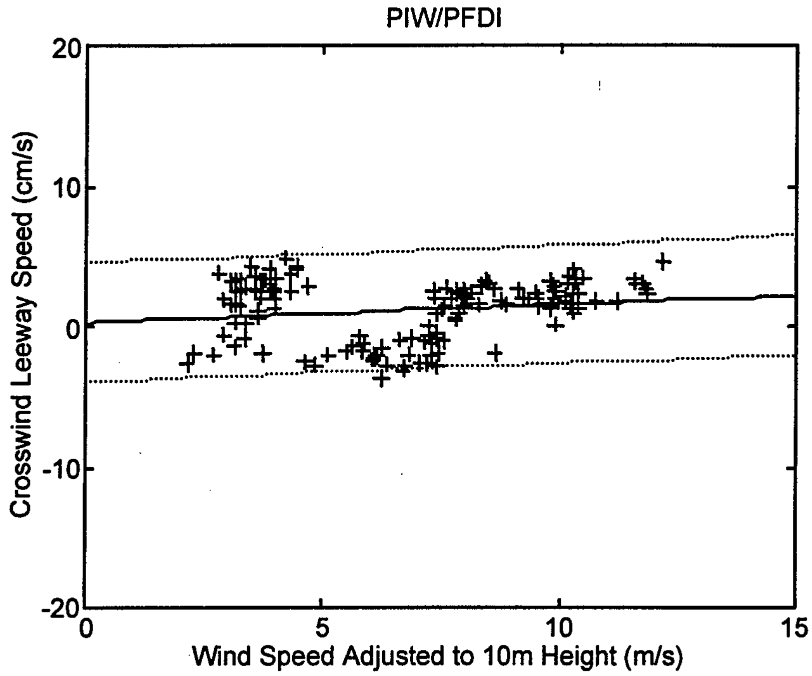


Figure 4-29. Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Person-In-Water in a Type I Personal Flotation Device

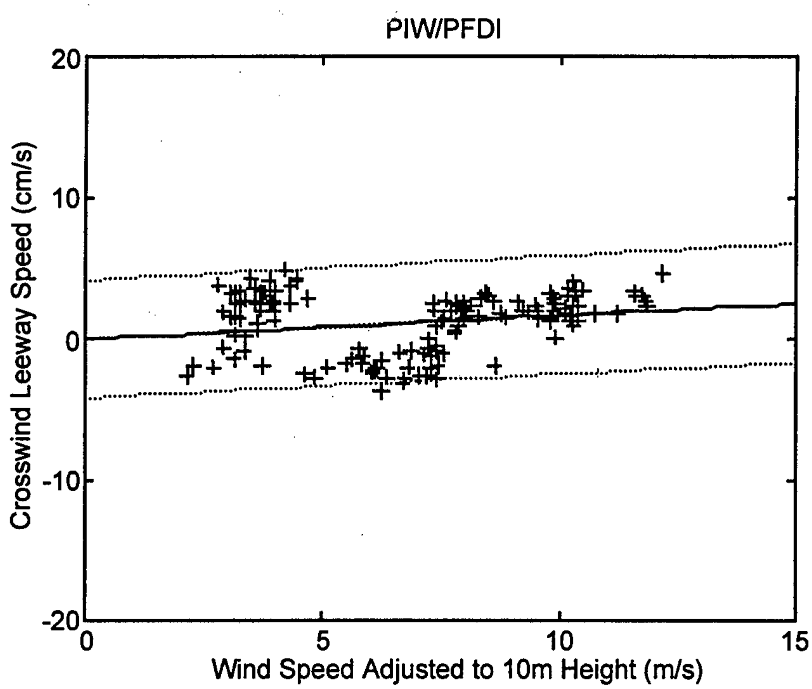


Figure 4-30. Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Type I Personal Flotation Device

Table 4-27. **Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Type I Personal Flotation Device**

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	121 & 126	144	0.33	0.13	0.03	2.11	2.1 – 12.2
Constrained	121 & 126	144	–	0.17	0.02	2.11	2.1 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-28. The curves are displayed on Figure 4-29 for the unconstrained case and on Figure 4-30 for the constrained case.

Table 4-28. **The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Type I Personal Flotation Device**

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	0.101	4.601	-0.002	0.152	-3.943
Constrained	0.000	0.168	4.163	0.000	0.168	-4.163

4-3.2 Person-In-Water with Survival Suit (PIW-SS)

The PIW-SS was deployed between 21/1825 January and 23/0710 January 1998 for leeway run #119, between 26/1931 January and 27/0455 January 1998 for leeway run #122, and again between 30/0841 January and 01/1250 February 1998 for leeway run #125. Total usable data from these three runs amounted to 59 hours and 6 minutes of drift data (Table 3-4). W_{10m} varied between 2.0 m/s and 12.2 m/s. Wave height, H_s, varied between 0.7 m and 2.7 m (Table 3-4).

4-3.2.1 PIW-SS Leeway Speed and Angle

Leeway speeds as a function of W_{10m} for the PIW-SS are presented in Figures 4-31 and 4-32. Figure 4-31 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or leeway speed at W_{10m}=0 is 5.2 cm/s, the slope of the regression line is 1.4%, and the standard error of estimate is ±1.85 cm/s (Table 4-29). For the constrained case (Figure 4-32) the slope of the regression line is 2.2% with a standard error of

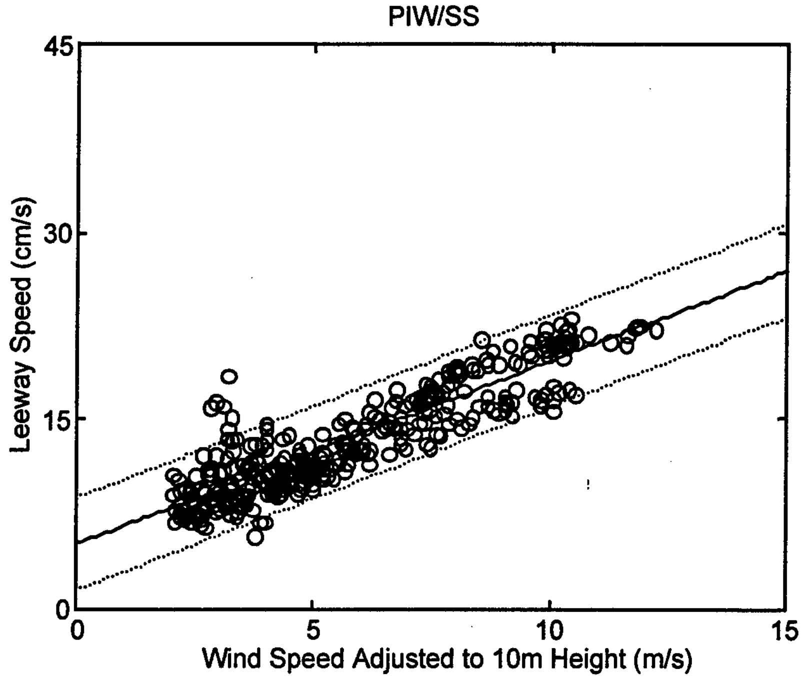


Figure 4-31. Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Survival Suit

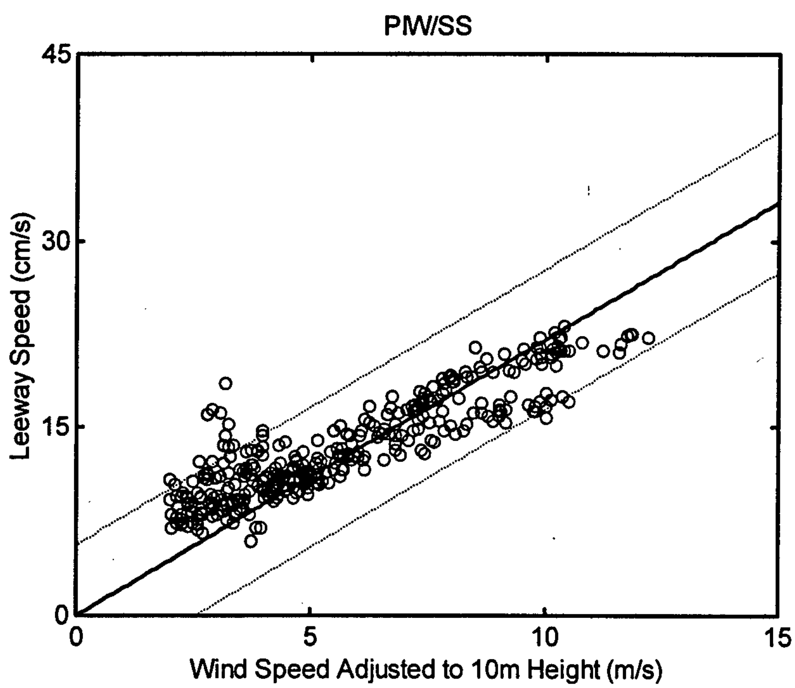


Figure 4-32. Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Survival Suit

estimate of ±2.85 cm/s. An r^2=0.80 for the unconstrained case indicates that 80% of the variance of leeway speed for the PIW-SS is explained by using W_{10m} as a predictor. This value of r^2 indicates that W_{10m} is an excellent predictor of leeway speed. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.53. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case W_{10m} is not as good a predictor as in the unconstrained case.

Table 4-29. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Survival Suit

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	119, 122, & 125	356	5.25	1.44	0.80	1.85	2.0 – 12.2
Constrained	119, 122, & 125	356	–	2.21	0.53	2.85	2.0 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-30. The curves are displayed on Figure 4-31 for the unconstrained case and on Figure 4-32 for the constrained case.

Table 4-30. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Survival Suit

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.001	1.434	8.917	-0.001	1.451	1.575
Constrained	0.000	2.206	5.606	0.000	2.206	-5.606

The mean leeway angle of drift with respect to the downwind direction was 18° to the right of the downwind direction when W_{10m} was greater than 5 m/s. For W_{10m} less than 5 m/s the leeway angle was distributed through a full range of angles (Figure 4-33). The greatest leeway angle to the left of downwind was 173° for all wind speeds and 24° for winds greater than 5 m/s (Table 4-31). The greatest leeway angle to the right of the downwind direction was 174° for all wind speeds and 42° for winds greater than 5 m/s. The mean leeway angle was 1° to the right of the wind direction for all winds and 18° to the right for wind speeds greater than 5 m/s. The standard deviation of the leeway angle was ±46° for all winds and ±20° for winds greater than 5 m/s. The mean of the absolute values of the leeway angle was 34° for all wind speeds and 24° for W_{10m} winds greater than 5 m/s. The standard deviations of the absolute values of the leeway angle were ±31° and ±9° respectively for all wind speeds and wind speeds greater than 5 m/s. For wind

speeds greater than 5 m/s the leeway angle was fairly stable but was greater than for the PIW-I case. The PIW-SS has greater exposure to the wind and the very near sea surface.

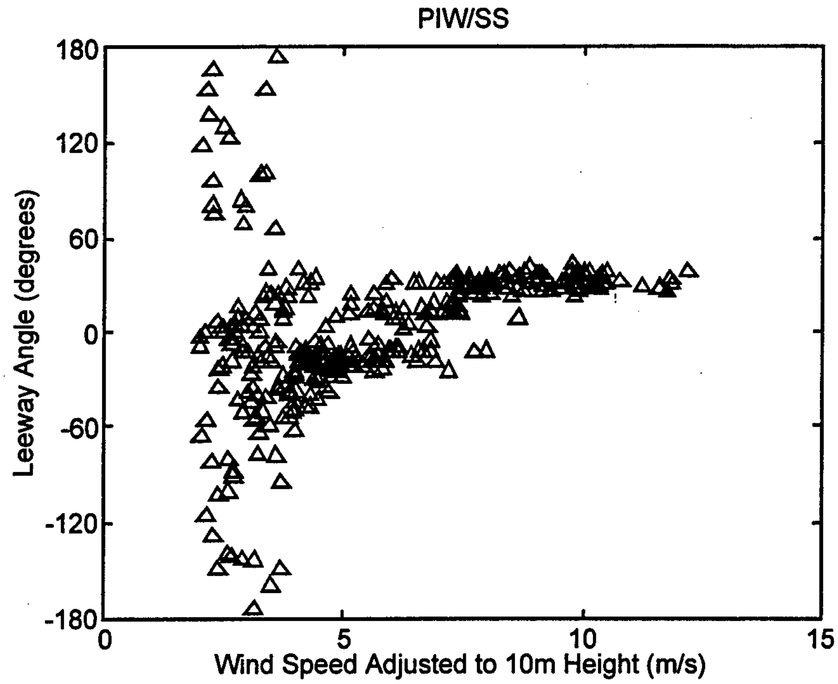


Figure 4-33. Leeway Angle (degrees) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Survival Suit

Table 4-31. Leeway Angle (degrees): Person-In-Water in a Survival Suit

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle mean	s.dev.	min	max	Abs. Angle mean	s.dev.
All Winds	356	2.0 – 12.2	1	46	-173	174	34	31
Winds > 5 m/s	178	5.0 – 12.2	18	20	-24	42	24	9

4-3.2.2 PIW-SS Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the PIW-SS is shown in Figures 4-34 and 4-35. The unconstrained (Figure 4-34) and the constrained (Figure 4-35) linear regression along with the 95% prediction limits are shown for leeway runs #119, #122, and #125. Table 4-32 summarizes the regressions for the unconstrained and constrained cases for **DWL** and Table 4-33 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-34) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 1.1 cm/s, the slope of the regression line is 1.7%, and the standard error of estimate is ±3.93 cm/s (Table 4-32). For the constrained case (Figure 4-35) the slope of the regression line is 1.9% with a standard error of estimate of ±3.95 cm/s. An r^2=0.56 for

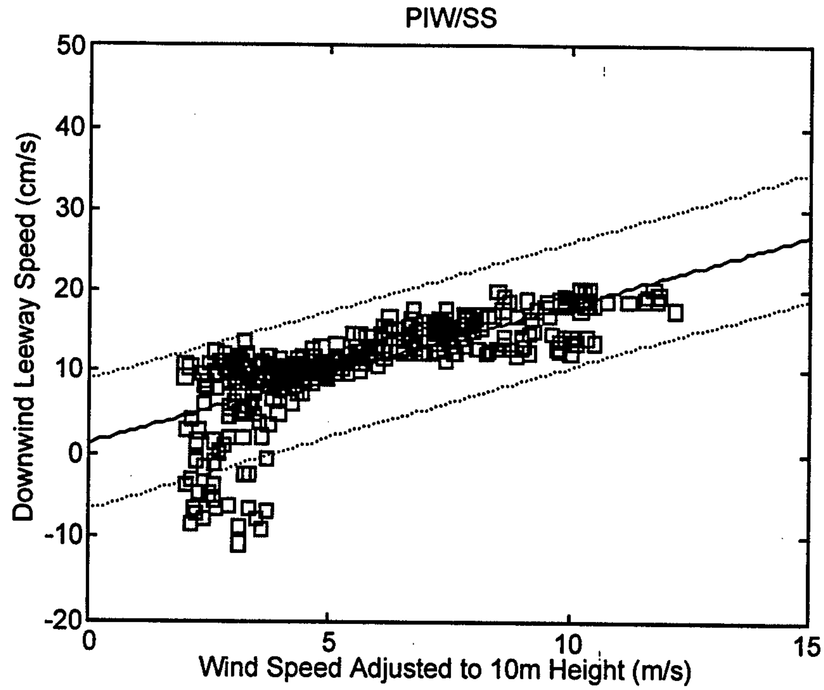


Figure 4-34. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Survival Suit

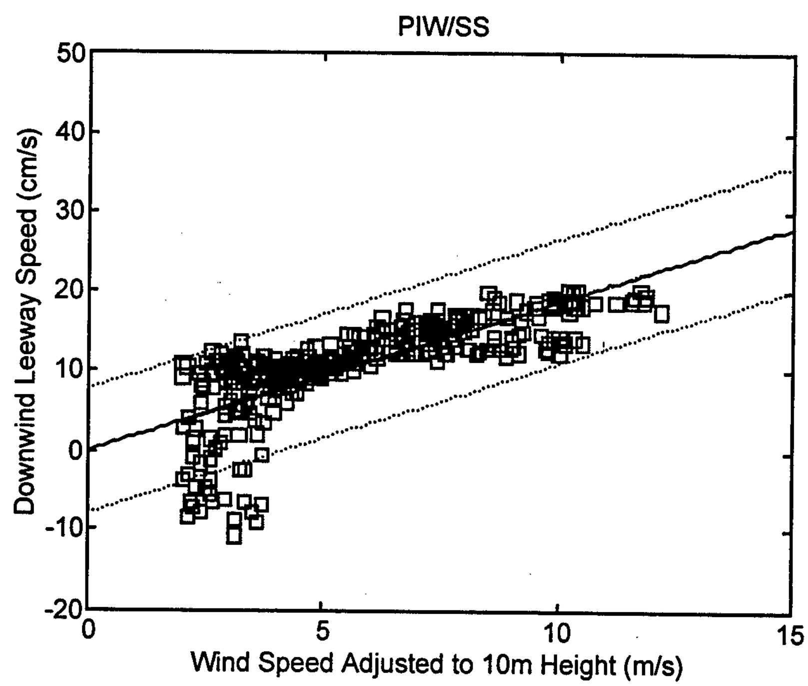


Figure 4-35. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Person-In-Water in a Survival Suit

the unconstrained case indicates that 56% of the variance of **DWL** for the PIW-SS is explained by using $\mathbf{W_{10m}}$ as a predictor. $\mathbf{W_{10m}}$ is a fair predictor of **DWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.55. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is as good a predictor as in the unconstrained case. Since the y-axis intercept value is small in the unconstrained case a similar value of r^2 is to be expected.

Table 4-32. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Survival Suit

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	119, 122, & 125	356	1.12	1.71	0.56	3.93	2.0 – 12.2
Constrained	119, 122, & 125	356	–	1.87	0.55	3.95	2.0 – 12.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-33. The curves are displayed on Figure 4-34 for the unconstrained case and on Figure 4-35 for the constrained case.

Table 4-33. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Survival Suit

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	1.690	8.903	-0.002	1.727	-6.671
Constrained	0.000	1.871	7.766	0.000	1.871	-7.766

The crosswind component of leeway (**CWL**) as a function of $\mathbf{W_{10m}}$ for the PIW-SS is shown in Figures 4-36 and 4-37. The unconstrained (Figure 4-36) and the constrained (Figure 4-37) linear regression along with the 95% prediction limits are shown for leeway runs #119, #122, and #125. Table 4-34 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-35 summarizes the 95% prediction limits.

CWL for the PIW-SS had both positive and negative values represented in the data set, and the data set was large enough to analyze the positive and negative values separately. Since the **CWL** at low wind speeds is unstable and the data are very scattered, only data for $\mathbf{W_{10m}}$ greater than 5 m/s were analyzed.

For the unconstrained case (Figure 4-36) the y-axis intercept or leeway speed at $W_{10m} = 0$ is –3.3 cm/s for positive **CWL** and –2.6 cm/s for negative **CWL**. The slope of the regression line is 1.4% for positive **CWL** and –0.1% for negative **CWL**. The standard error of estimates for the unconstrained case are ±1.71 cm/s and ±1.62 cm/s for the positive and negative **CWL** respectively (Table 4-34). An $r^2 = 0.63$ for the unconstrained regression case indicates that 63% of the variance of the positive **CWL** for the PIW-SS is explained by using $\mathbf{W_{10m}}$ as a predictor. For the unconstrained negative **CWL** $r^2 = 0.00$ indicates that $\mathbf{W_{10m}}$ has no value as a predictor of negative **CWL** since its use does not explain the variance of the negative **CWL**. This result arises not from the fact that the negative **CWL** does not fit the linear model but from the fact that, in this data set, the PIW-SS moves only slightly to the left of the downwind direction. Therefore $\mathbf{W_{10m}}$ is a good predictor of positive **CWL** and no predictor of negative **CWL** for the unconstrained cases. In the case of constrained regression of leeway speed on $\mathbf{W_{10m}}$ (Figure 4-37) the slope of the regression line is 1.0% for positive **CWL** and –0.6% for negative **CWL**. The standard error of estimates are ±1.82 cm/s and ±1.63 cm/s respectively for positive and negative **CWL** (Table 4-34). The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.58 for positive **CWL** and –0.04 for negative CWL. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case of positive **CWL** $\mathbf{W_{10m}}$ is a fair predictor and for the constrained case of negative **CWL** $\mathbf{W_{10m}}$ has no predictive value.

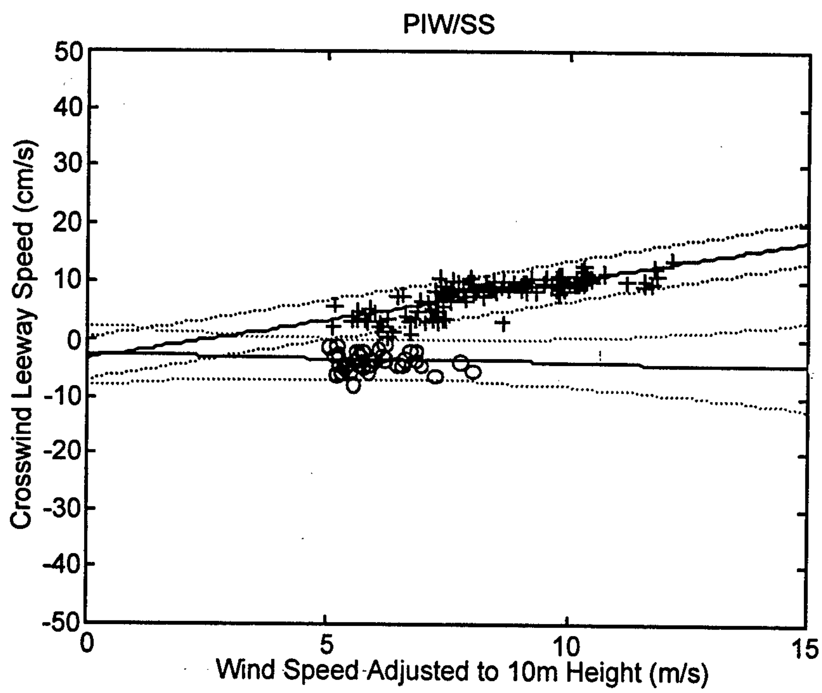


Figure 4-36. Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Person-In-Water in a Survival Suit (+ - Positive CWL, O – Negative CWL)

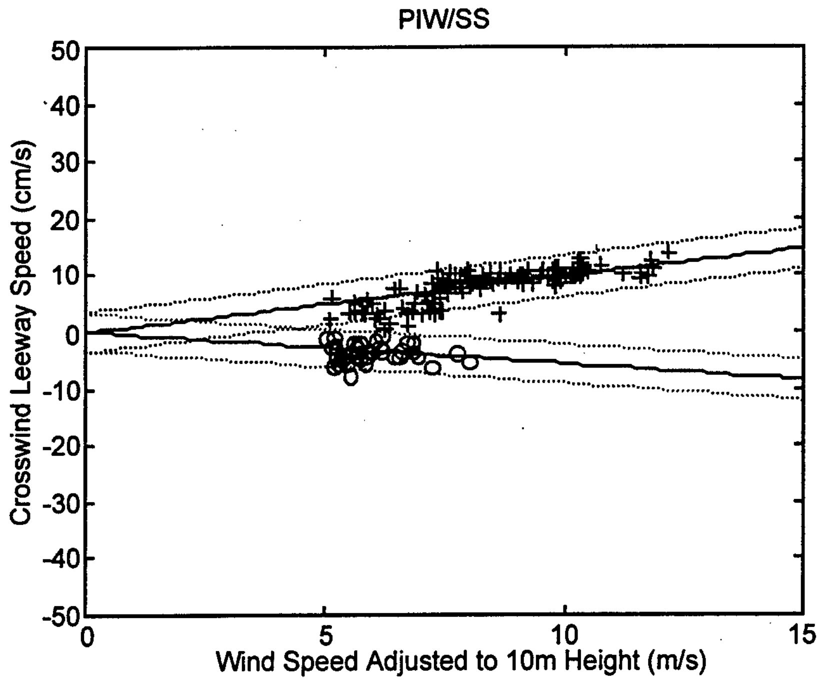


Figure 4-37. Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Person-In-Water in a Survival Suit (+ - Positive CWL, O – Negative CWL)

Table 4-34. Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Survival Suit

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained (Positive CWL)	119, 122, & 125	136	-3.30	1.36	0.63	1.71	5.0 – 12.2
Constrained (Positive CWL)	119, 122, & 125	136	–	0.98	0.58	1.82	5.0 – 12.2
Unconstrained (Negative CWL)	119, 122, & 125	37	-2.65	-0.13	0.00	1.62	5.0 – 8.0
Constrained (Negative CWL)	119, 122, & 125	37	–	-0.57	-0.04	1.63	5.0 – 8.0

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-35. The curves are displayed on Figure 4-36 for the unconstrained case and on Figure 4-37 for the constrained case.

Table 4-35. **The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Person-In-Water in a Survival Suit**

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained (Positive **CWL**)	0.004	1.284	0.407	-0.004	1.432	-7.003
Constrained (Positive **CWL**)	0.000	0.981	3.590	0.000	0.981	-3.590
Unconstrained (Negative **CWL**)	0.052	-0.753	2.711	-0.052	0.500	-8.001
Constrained (Negative **CWL**)	0.001	-0.565	3.302	-0.001	-0.566	-3.302

4-4 PERSONALLY POWERED WATER CRAFT

Two types of recreational water craft which are powered by their users or the wind were evaluated for leeway during the Delaware Bay test period.

4-4.1 Sea Kayak

A Sea Kayak was configured with a mannequin on the stern to simulate a drifting distressed Sea Kayak. This configuration was tested during the Delaware Bay leeway experiment. The Sea Kayak had a relatively high profile to the wind and a very small draft.

The Sea Kayak was deployed between 18/1747 January and 19/1948 January 1998 for leeway run #113, between 21/1738 January and 23/0703 January 1998 for leeway run #116, and again between 26/1911 January and 27/0422 January 1998 for leeway run #120. Total usable data from the first two runs amounted to 65 hours of drift data (Table 3-4). Run #120 had insufficient data and was not analyzed. $\mathbf{W_{10m}}$ varied between 2.0 m/s and 11.2 m/s. Wave height, H_s, varied between 0.7 m and 2.7 m (Table 3-4).

4-4.1.1 Sea Kayak Leeway Speed and Angle

Leeway speeds as a function of $\mathbf{W_{10m}}$ for the Sea Kayak are presented in Figures 4-38 and 4-39. Figure 4-38 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 12.5 cm/s, the slope of the regression line is 1.1%, and the standard error of estimate is ±3.52 cm/s (Table 4-36). For the constrained case (Figure 4-39) the slope of the regression line is 3.1% with a standard error of estimate of ±6.40

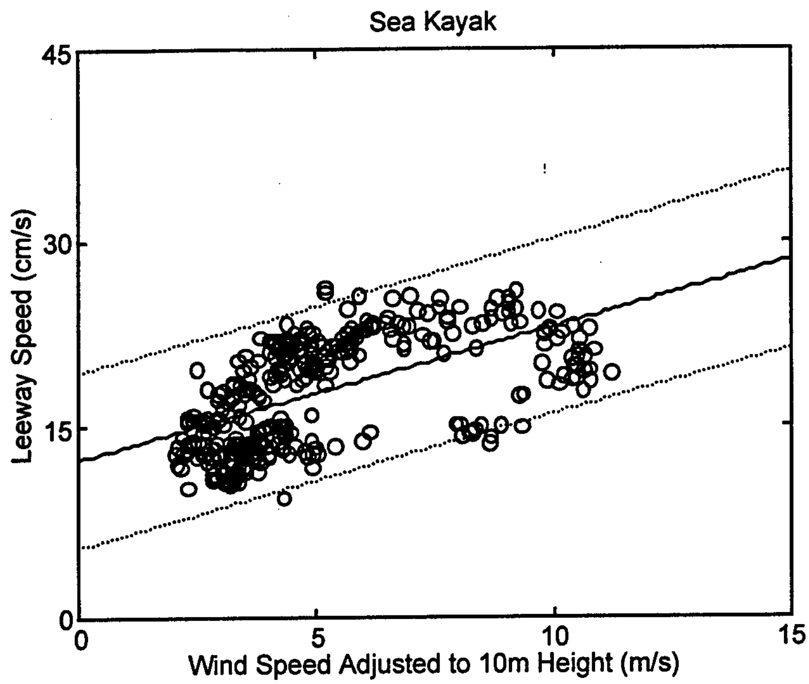


Figure 4-38. Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Sea Kayak

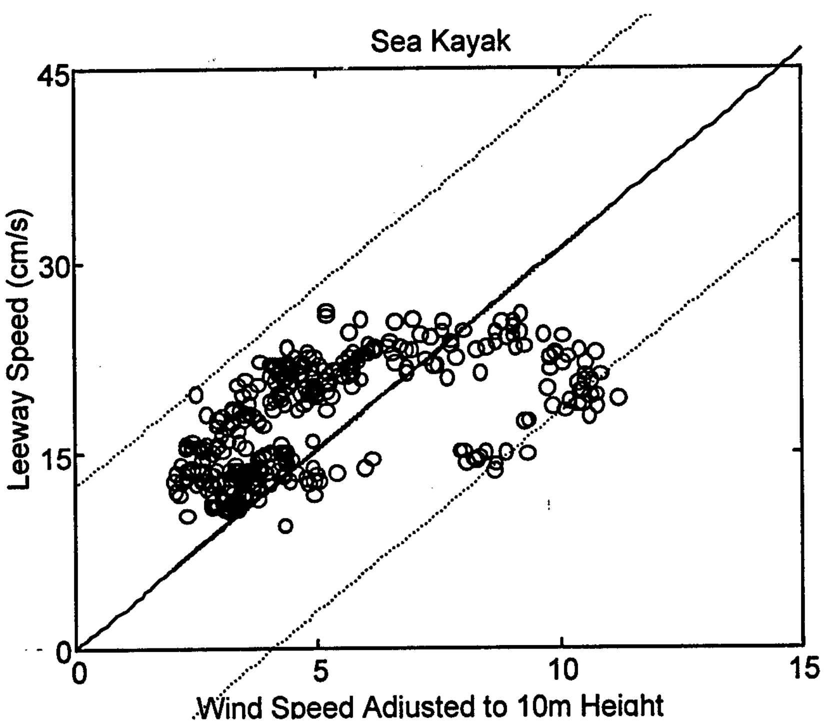


Figure 4-39. Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Sea Kayak

cm/s. An r^2=0.34 for the unconstrained case indicates that 34% of the variance of leeway speed for the Sea Kayak is explained by using W_{10m} as a predictor. This value of r^2, for

the unconstrained case, indicates that W_{10m} is only a poor predictor of leeway speed. The value of r^2 for the case where the regression line is constrained to pass through the origin is –1.19. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case W_{10m} is a much worse predictor of leeway speed than the mean leeway speed without a predictor.

Table 4-36. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Sea Kayak

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	113 & 116	345	12.51	1.06	0.34	3.52	2.0 – 11.2
Constrained	113 & 116	345	–	3.09	-1.19	6.40	2.0 – 11.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-37. The curves are displayed on Figure 4-38 for the unconstrained case and on Figure 4-39 for the constrained case.

Table 4-37. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Sea Kayak

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	1.044	19.482	-0.002	1.079	5.532
Constrained	0.001	3.093	12.587	-0.001	3.093	-12.587

The mean leeway angle of drift for the Sea Kayak, with respect to the downwind direction, was 7° to the right of the downwind direction when W_{10m} was greater than 5 m/s (Figure 4-40). For all winds, the mean leeway angle was 9° to the right of the wind. The greatest leeway angle to the left of downwind was 40° for all wind speeds and 17° for winds greater than 5 m/s (Table 4-38). The greatest leeway angle to the right of the downwind direction was 61° for all wind speeds and 43° for winds greater than 5 m/s. The standard deviation of the leeway angle was ±18° for all winds and ±10° for winds greater than 5 m/s. The mean of the absolute values of the leeway angle was 15° for all wind speeds and 10° for W_{10m} winds greater than 5 m/s. The standard deviations of the absolute values of the leeway angle were ±13° and ±7° respectively for all wind speeds and wind speeds greater than 5 m/s. For the wind speeds greater than 5 m/s the leeway angle was fairly stable.

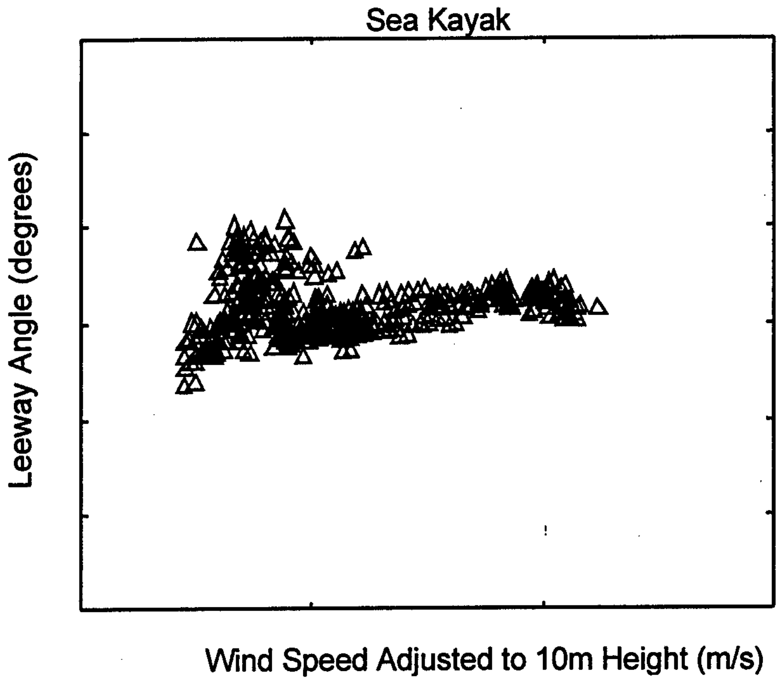


Figure 4-40. Leeway Angle (degrees vs. 10m Wind Speed (m/s) for the Sea Kayak

Table 4-38. Leeway Angle (degrees): Sea Kayak

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle mean	s.dev.	min	max	Abs. Angle mean	s.dev.
All Winds	345	2.0 – 11.2	9	18	-40	61	15	13
Winds > 5 m/s	119	5.0 – 11.2	7	10	-17	43	10	7

4-4.1.2 Sea Kayak Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the Sea Kayak is shown in Figures 4-41 and 4-42. The unconstrained (Figure 4-41) and the constrained (Figure 4-42) linear regression along with the 95% prediction limits are shown for leeway runs #113 and #116. Table 4-39 summarizes the regressions for the unconstrained and constrained cases for **DWL** and Table 4-40 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-41) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 11.1 cm/s, the slope of the regression line is 1.2%, and the standard error of estimate is ±4.12 cm/s (Table 4-39). For the constrained case (Figure 4-42) the slope of the regression line is 3.0% with a standard error of estimate of ±6.29 cm/s. An r^2=0.31 for the unconstrained case indicates that 31% of the variance of **DWL** for the Sea Kayak is

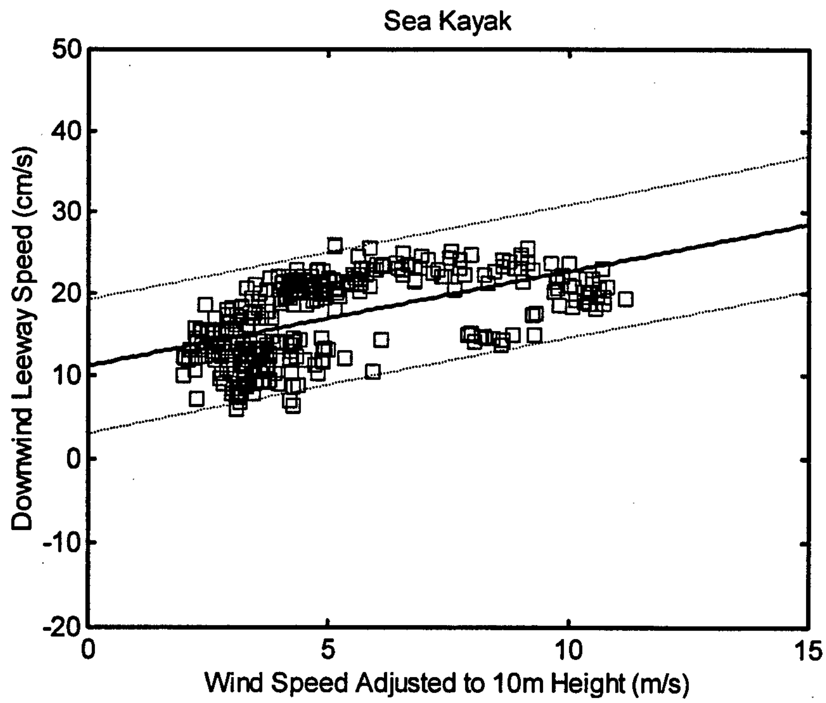


Figure 4-41. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Sea Kayak

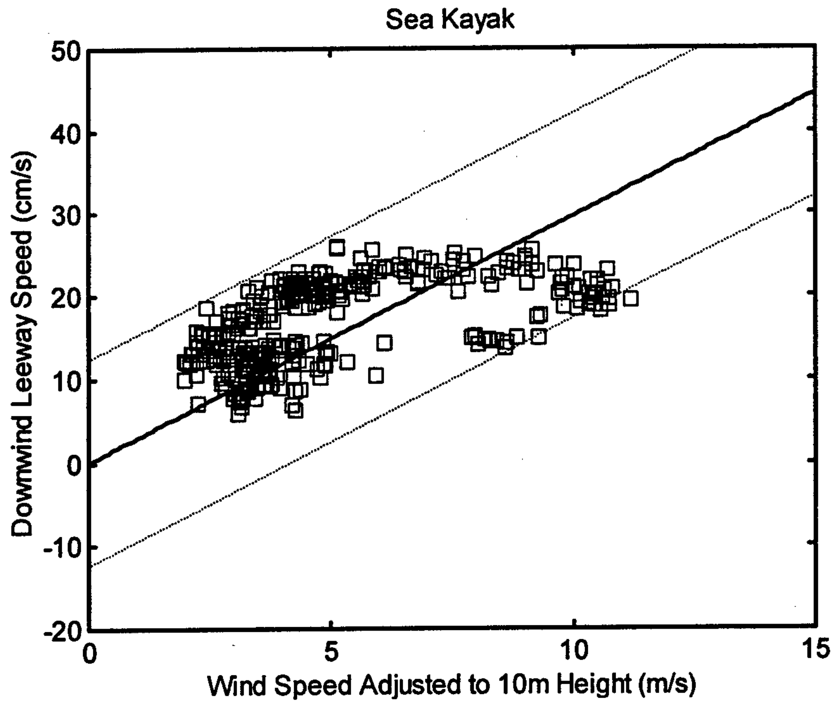


Figure 4-42. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Sea Kayak

Explained by using $\mathbf{W_{10m}}$ as a predictor. This means that $\mathbf{W_{10m}}$ is a poor predictor of **DWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is -0.61. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ has no predictive value in determining **DWL**.

Table 4-39. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Sea Kayak

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	113 & 116	345	11.12	1.16	0.31	4.12	2.0 – 11.2
Constrained	113 & 116	345	–	2.97	-0.61	6.29	2.0 – 11.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-40. The curves are displayed on Figure 4-41 for the unconstrained case and on Figure 4-42 for the constrained case.

Table 4-40. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Sea Kayak

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	1.144	19.280	-0.002	1.186	2.953
Constrained	0.001	2.971	12.364	-0.001	2.971	-12.364

The crosswind component of leeway (**CWL**) as a function of $\mathbf{W_{10m}}$ for the Sea Kayak is shown in Figures 4-43 and 4-44. For the two leeway runs #113 and #116 for the Sea Kayak, the **CWL** component was typically small with points distributed to both the positive and negative side of **CWL**. Therefore the data on **CWL** from the various runs were combined for **CWL** analysis. The unconstrained (Figure 4-43) and the constrained (Figure 4-44) linear regression along with the 95% prediction limits are shown for leeway runs #113 and #116. Table 4-41 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-42 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-43) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}=0$ is 0.0 cm/s, the slope of the regression line is 0.4%, and the standard error of estimate is ±4.39 cm/s (Table 4-41). For the constrained case (Figure 4-44) the slope of the regression line is 0.4% with a standard error of estimate of ±4.38 cm/s. An $r^2=0.48$ for the unconstrained case indicates that 48% of the variance of **CWL** for the Sea Kayak is explained by using $\mathbf{W_{10m}}$ as a predictor. This value of r^2 indicates that $\mathbf{W_{10m}}$ is a fair predictor of **CWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is also 0.48. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case $\mathbf{W_{10m}}$ is as good a predictor as in the unconstrained case since in the unconstrained case the y-axis intercept is also at the origin.

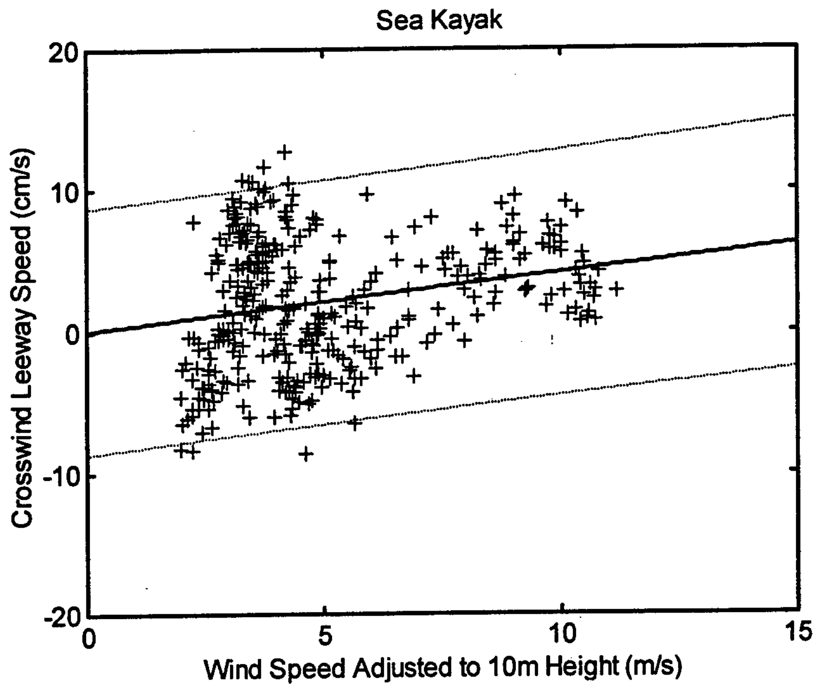


Figure 4-43. Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Sea Kayak

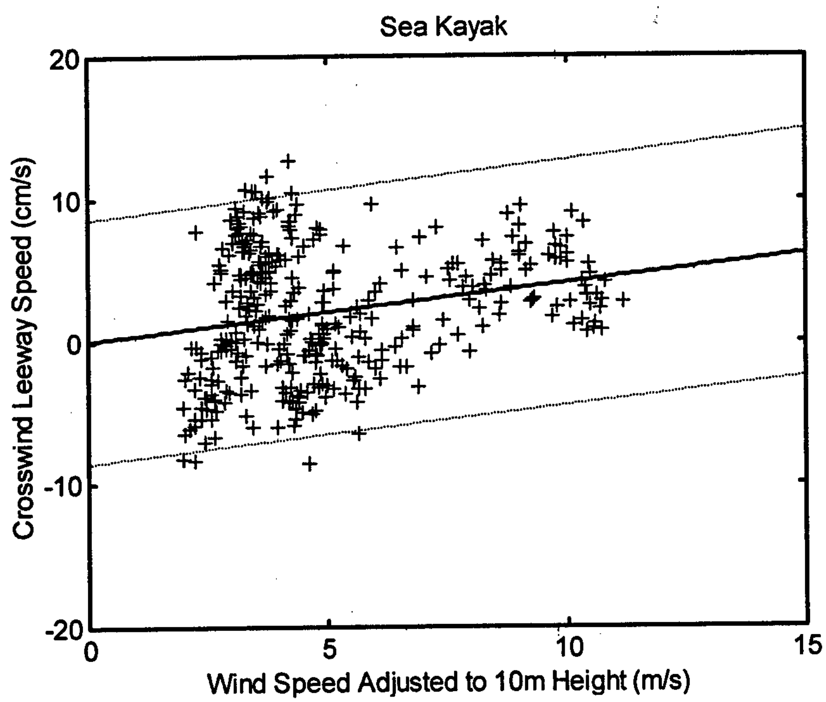


Figure 4-44. Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Sea Kayak

Table 4-41. **Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Sea Kayak**

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	113 & 116	345	0.00	0.41	0.48	4.39	2.0 – 11.2
Constrained	113 & 116	345	–	0.41	0.48	4.38	2.0 – 11.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-42. The curves are displayed on Figure 4-43 for the unconstrained case and on Figure 4-44 for the constrained case.

Table 4-42. **The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Sea Kayak**

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	0.391	8.690	-0.002	0.435	-8.699
Constrained	0.000	0.413	8.614	0.000	0.413	-8.614

4-4.2 Windsurfer

A high buoyancy/high volume type Windsurfer was chosen to simulate a type of leeway object frequently used in coastal areas. The configuration used in the Delaware Bay leeway experiments was not equipped with mast or sail but did have a mannequin attached to the stern to simulate an operator.

The Windsurfer was deployed between 18/1725 January and 19/1738 January 1998 for leeway run #115, between 21/1816 January and 23/0630 January 1998 for leeway run #118, and again between 26/1932 January and 27/0507 January 1998 for leeway run #123. The initial ten data samples from run #115 were not included in the analysis because an apparent frontal wind shift made the extrapolation of wind velocity from the WeatherPak® mounted on the Wharf Box unreliable. Total usable data from runs #115 and #118 amounted to 59 hours and 38 minutes of drift data (Table 3-4). Data from run # 123 were of insufficient quality and were not used in the analysis. $\mathbf{W_{10m}}$ varied between 2.0 m/s and 11.2 m/s. Wave height, H_s, varied between 0.7 m and 2.7 m (Table 3-4).

4-4.2.1 Windsurfer Leeway Speed and Angle

Leeway speeds as a function of $\mathbf{W_{10m}}$ for the Windsurfer are presented in Figures 4-45 and 4-46. Figure 4-45 presents the data fitted with an unconstrained regression line and with associated 95% prediction limits. For the unconstrained case the y-axis intercept or

leeway speed at W_{10m}= 0 is 5.2 cm/s, the slope of the regression line is 2.3%, and the standard error of estimate is ±2.32 cm/s (Table 4-43). For the constrained case (Figure 4-46) the slope of the regression line is 3.3% with a standard error of estimate of ±3.09 cm/s. An r^2=0.78 for the unconstrained case indicates that 78% of the variance of leeway speed for the Windsurfer is explained by using W_{10m} as a predictor. This value of r^2, for the unconstrained case, indicates that W_{10m} is a good predictor of leeway speed. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.62. For the constrained case r^2 has no clear meaning (Section 3-2.2) indicates that for the constrained case W_{10m} is not as good a predictor of leeway speed as in the unconstrained case.

Table 4-43. Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Windsurfer

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	115 & 118	313	5.24	2.30	0.78	2.32	2.0 – 11.2
Constrained	115 & 118	313	–	3.28	0.62	3.09	2.0 – 11.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-44. The curves are displayed on Figure 4-45 for the unconstrained case and on Figure 4-46 for the constrained case.

Table 4-44. **The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Leeway Speed (cm/s) on 10m Wind Speed (m/s): Windsurfer**

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	2.282	9.863	-0.002	2.317	0.625
Constrained	0.000	3.276	6.080	0.000	3.276	-6.080

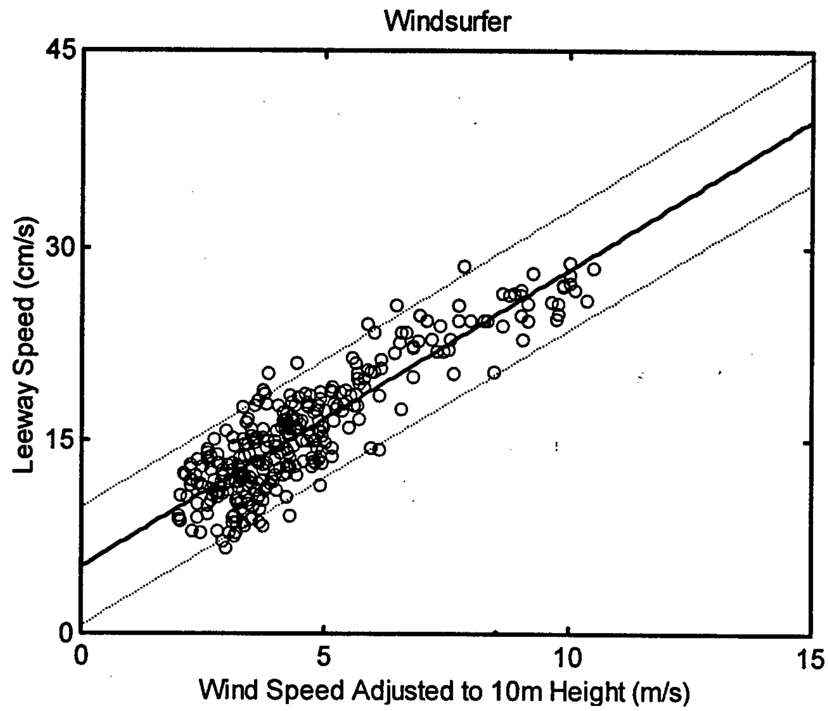


Figure 4-45. Unconstrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Windsurfer

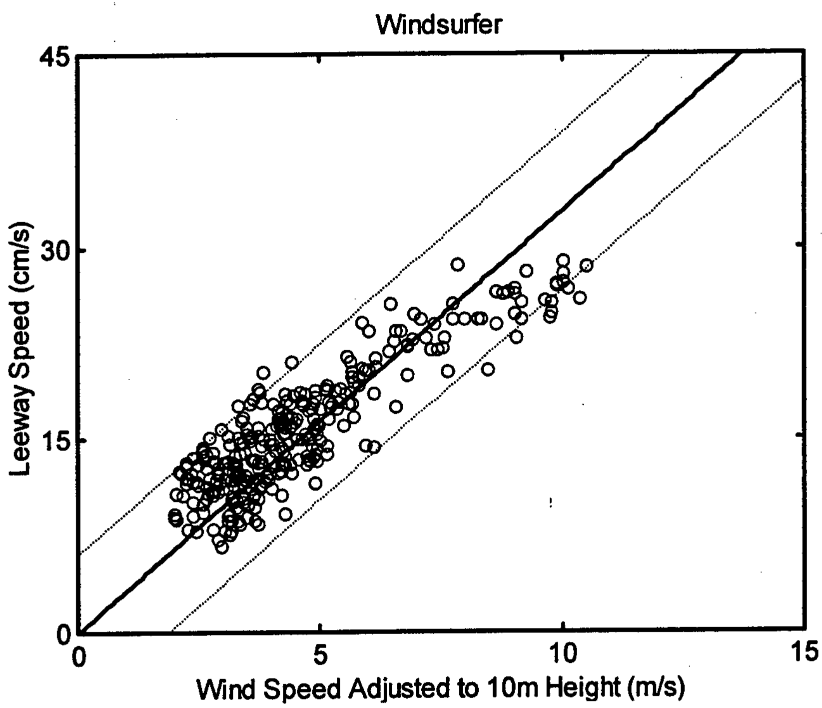


Figure 4-46. Constrained Regression and 95% Prediction Limits of Leeway Speed (cm/s) vs. 10m Wind Speed (m/s) for the Windsurfer

The mean leeway angle of drift for the Windsurfer, with respect to the downwind direction, was 8° to the left of the downwind direction when $\mathbf{W_{10m}}$ was greater than 5 m/s and 6° to the left of the wind direction for all winds (Figure 4-47). The greatest leeway angle to the left of downwind was 43° for all wind speeds and 34° for winds greater than 5 m/s (Table 4-45). The greatest leeway angle to the right of the downwind direction was 27° for all wind speeds and 7° for winds greater than 5 m/s. The standard deviation of the leeway angle was ±13° for all winds and ±8° for winds greater than 5 m/s. The mean of the absolute values of the leeway angle was 11° for all wind speeds and 9° for $\mathbf{W_{10m}}$ winds greater than 5 m/s. The standard deviations of the absolute values of the leeway angle were ±9° and ±7° respectively for all wind speeds and wind speeds greater than 5 m/s. The leeway angle was relatively stable at all measured wind speeds.

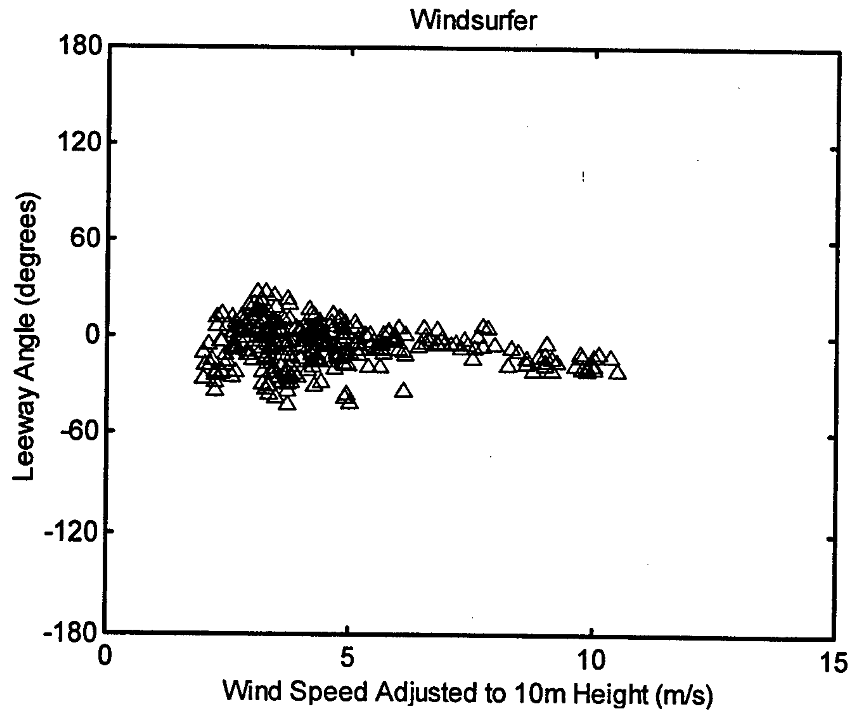


Figure 4-47. Leeway Angle (degrees) vs. 10m Wind Speed (m/s) for the Windsurfer

Table 4-45. Leeway Angle (degrees): Windsurfer

Analysis Case	# samples	W_{10m} (m/s)	Leeway Angle mean	s.dev.	min	max	Abs. Angle mean	s.dev.
All Winds	313	2.0 – 11.2	-6	13	-43	27	11	9
Winds > 5 m/s	86	5.0 – 11.2	-8	8	-34	7	9	7

4-4.2.2 Windsurfer Downwind and Crosswind Leeway Components

The downwind component of leeway (**DWL**) as a function of $\mathbf{W_{10m}}$ for the Windsurfer is shown in Figures 4-48 and 4-49. The unconstrained (Figure 4-48) and the constrained (Figure 4-49) linear regression along with the 95% prediction limits are shown for leeway runs #115 and #118. Table 4-46 summarizes the regressions for the unconstrained and constrained cases for **DWL** and Table 4-47 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-48) the y-axis intercept or leeway speed at $\mathbf{W_{10m}}$=0 is 5.0 cm/s, the slope of the regression line is 2.2%, and the standard error of estimate is ±2.50 cm/s (Table 4-46). For the constrained case (Figure 4-49) the slope of the regression line is 3.2% with a standard error of estimate of ±3.17 cm/s. An r^2=0.75 for the unconstrained case indicates that 75% of the variance of **DWL** for the Windsurfer is explained by using $\mathbf{W_{10m}}$ as a predictor. This means that $\mathbf{W_{10m}}$ is a good predictor of **DWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is 0.60. For the constrained case r^2 has no clear meaning (Section 3-

2.2) indicates that for the constrained case $\mathbf{W_{10m}}$ is a poorer predictor of **DWL** than for the unconstrained case.

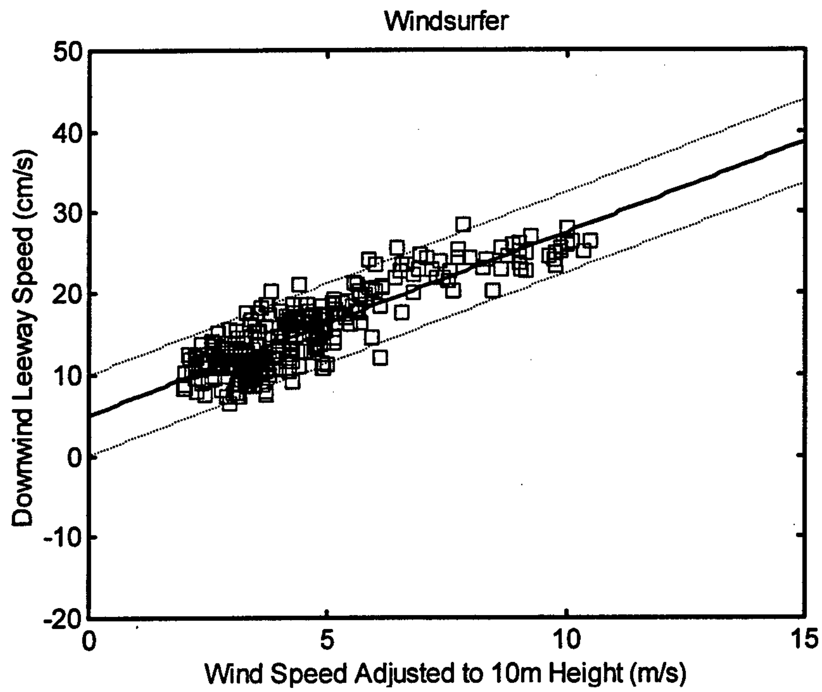


Figure 4-48. Unconstrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Windsurfer

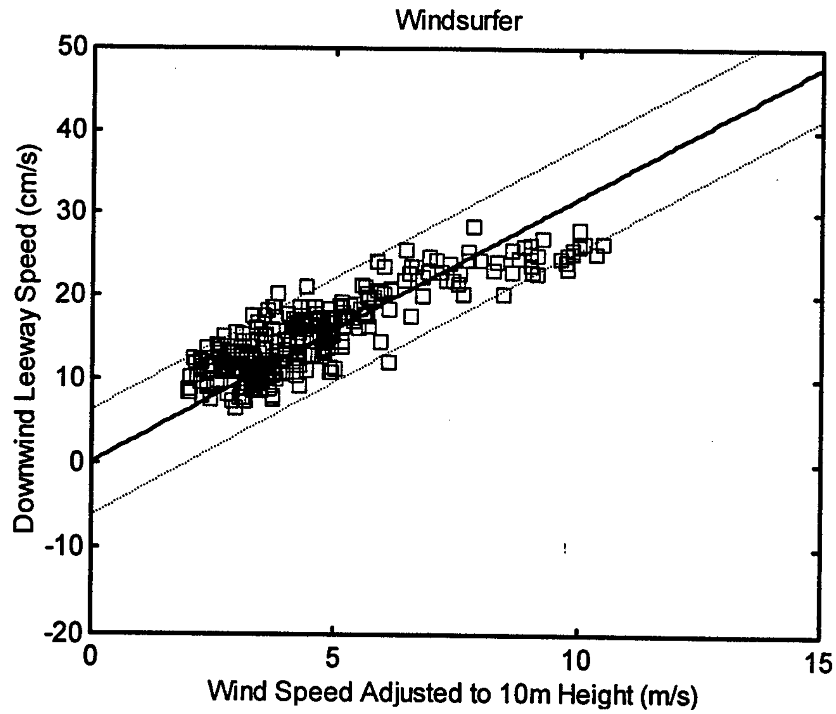


Figure 4-49. Constrained Regression and 95% Prediction Limits of Downwind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Windsurfer

Table 4-46. Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Windsurfer

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	115 & 118	313	5.01	2.25	0.75	2.50	2.0 – 11.2
Constrained	115 & 118	313	–	3.18	0.60	3.17	2.0 – 11.2

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-47. The curves are displayed on Figure 4-48 for the unconstrained case and on Figure 4-49 for the constrained case.

Table 4-47. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Downwind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Windsurfer

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	2.230	9.999	-0.002	2.268	0.054
Constrained	0.000	3.185	6.241	0.000	3.185	-6.241

The crosswind component of leeway (**CWL**) as a function of W_{10m} for the Windsurfer is shown in Figures 4-50 and 4-51. For leeway runs #115 and #118 the majority of the Windsurfer **CWL** values were negative. For all runs the regression line tended to the negative (or left) side. Therefore the two data sets were combined for **CWL** analysis. The unconstrained (Figure 4-50) and the constrained (Figure 4-51) linear regression along with the 95% prediction limits are shown for leeway runs #115 and #118. Table 4-48 summarizes the regressions for the unconstrained and constrained cases for **CWL** and Table 4-49 summarizes the 95% prediction limits. For the unconstrained case (Figure 4-50) the y-axis intercept or leeway speed at W_{10m}=0 is 1.3 cm/s, the slope of the regression line is –0.7%, and the standard error of estimate is ±2.96 cm/s (Table 4-48). For the constrained case (Figure 4-51) the slope of the regression line is -0.4% with a standard error of estimate of ±3.00 cm/s. An r^2=0.17 for the unconstrained case indicates that 17% of the variance of **CWL** for the Windsurfer is explained by using W_{10m} as a predictor. This value of r^2 indicates that W_{10m} is a poor predictor of **CWL** no better than the mean of **CWL**. The value of r^2 for the case where the regression line is constrained to pass through the origin is also 0.14. For the constrained case r^2 has no clear meaning (Section 3-2.2) but indicates that for the constrained case W_{10m} is a poor predictor of **CWL**.

Table 4-48. Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Windsurfer

Analysis Case	Leeway Run	# samples	a	b	r^2	$S_{y/x}$	W_{10m} (m/s)
Unconstrained	115 & 118	313	1.30	-0.69	0.17	2.96	2.0 – 11.2
Constrained	115 & 118	313	–	-0.45	0.14	3.00	2.0 – 11.2

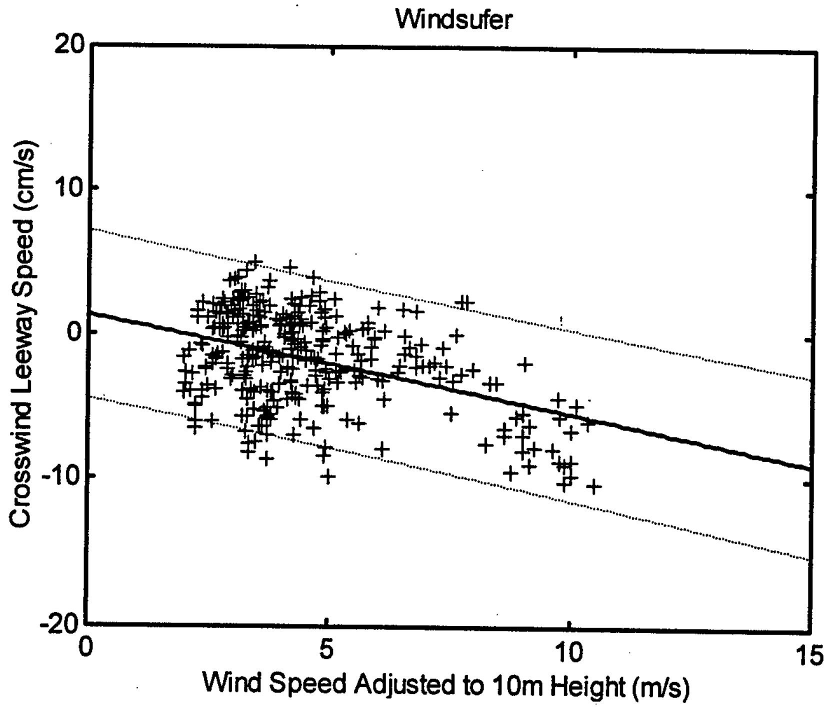


Figure 4-50. Unconstrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for Windsurfer

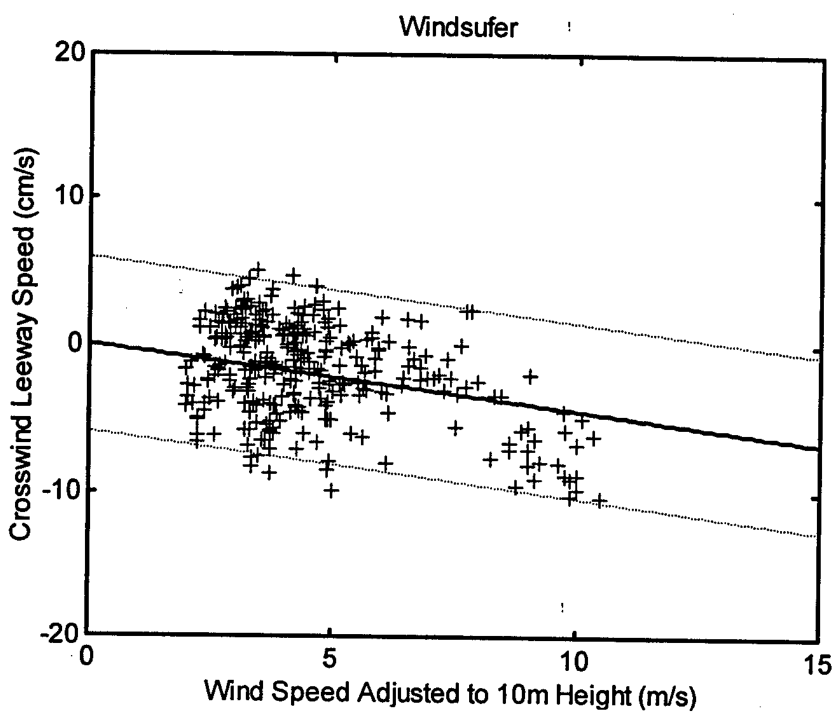


Figure 4-51. Constrained Regression and 95% Prediction Limits of Crosswind Component of Leeway (cm/s) vs. 10m Wind Speed (m/s) for the Windsurfer

The coefficients of the second order equation defining the 95% prediction limits bounding the regression line are presented in Table 4-49. The curves are displayed on Figure 4-50 for the unconstrained case and on Figure 4-51 for the constrained case.

Table 4-49. The Coefficients of the Polynomials Describing 95% Prediction Limits of the Linear Regression of Crosswind Component of Leeway (cm/s) on 10m Wind Speed (m/s): Windsurfer

Analysis Case	Upper limits			Lower Limits		
	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3	$c_1(W_{10m})^2$	$c_2(W_{10m})$	c_3
Unconstrained	0.002	-0.712	7.181	-0.002	-0.667	-4.585
Constrained	0.000	-0.448	5.897	0.000	-0.448	-5.897

4-5 NON-ZERO LEEWAY AT ZERO W_{10m}

In virtually all cases where the unconstrained leeway speed is computed as a function of wind speed (W_{10m}) the y-axis (leeway speed) intercept is positive and non-zero. The interpretation of this behavior is that leeway is not zero when the wind speed is zero. There are two possible explanations. The first is that the slope of the leeway function is not linear throughout the range of winds measured or if it is linear the slope of the function changes at some critical wind speed, such as 5 m/s. This would result in a leeway function that passes through zero and connects with a regression line at the critical wind speed. A look at the data in the figures of this chapter for leeway speed vs. wind speed shows no evidence of this phenomenon. The linearity of the leeway regression vs. W_{10m} continues down to the lowest wind speed observed, which in most of the data sets in this report are below 2 m/s. The second possible explanation of the non-zero leeway speed at zero wind speed is that the shear in the surface water layer can lead to movement of the object relative to the selected background reference current. Surface currents in these leeway tests were measured at a depth of 0.7 m to 1.1 m. If a particular leeway object had a draft much less or much greater than the depth at which currents were measured the object would have a non-zero speed relative to the 0.7 m to 1.1 m layer. The authors feel that this is the most reasonable explanation of this phenomenon. A possible example of the difference that draft can produce can be seen in the plots for the PIW-SS and the PIW-I. The PIW-SS is an extremely shallow draft object and has a zero wind speed leeway of 5.2 cm/s. The PIW-I because of its more vertical orientation has a relatively deep draft, extending into the 0.7 to 1.1 m zone where the current was measured. The zero wind speed leeway for the PIW-I is only 0.2 cm/s.

Another example that fits this latter hypothesis is from Allen (1996). In that report the leeway speed vs. the W_{10m} wind speed regression has a y-axis intercept (leeway speed) of 0.3 cm/s for a 15 m commercial fishing vessel. The draft of this fishing vessel was approximately 1.5 m. The current meter measuring the leeway was therefore centered in the layer affecting the vessel. The linear behavior of leeway speed vs. W_{10m} can be clearly seen down to the lowest wind speed encountered (1.3 m/s) during the testing of the commercial fishing vessel.

Also represented in Allen (1996) were leeway objects with very shallow draft such as a primitive raft of the type constructed by Cuban refugees. These rafts had a very shallow draft (approximately 0.08 m). The y-axis intercept (leeway speed) was 8.7 cm/s indicating a considerable leeway speed at a zero wind speed. The data in this case of leeway speed vs. wind speed also appeared to behave in a linear manner over the range of wind speeds observed.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5-1 SUMMARY

The leeway drift experiment conducted during January and February 1998 provided the basis for expanding the number of leeway drift objects for which leeway drift characteristics can be modeled based on the direct measurement of leeway. The September/October 1997 experiment conducted near Fort Pierce, Florida was designed to test the concept of using very small current meters to directly measure the leeway of small drift objects such as PIWs and personal watercraft. The configuration of the drift objects was modified and tested under the calmer conditions of Florida waters before the winter deployment in the waters offshore Delaware Bay.

The experiment conducted during the winter months of January and February 1998 near the mouth of Delaware Bay provided the range of winds (up to 12.2 m/s) and waves (up to 2.7 m) needed to provide statistically significant leeway values. A total of 309 drift object hours of leeway data were collected on the two types of PIW objects, a Windsurfer, a Sea Kayak, and two configurations of Wharf Box.

The data were sufficient to calculate the regression of leeway speed on $\mathbf{W_{10m}}$ winds, the 95% prediction limits of leeway speed vs. $\mathbf{W_{10m}}$ winds, the **DWL** components, and the **CWL** components. Only in the case of the PIW-SS object was sufficient negative **CWL** data present to allow separate analysis of positive **CWL** and negative **CWL**.

5-2 NON-ZERO LEEWAY AT ZERO $\mathbf{W_{10m}}$

There exist cases where the unconstrained leeway speed, computed as a function of wind speed ($\mathbf{W_{10m}}$), has a y-axis (leeway speed) intercept that is non-zero. The authors conclude in these cases, that the leeway speed is in fact non-zero when the ($\mathbf{W_{10m}}$) wind speed is zero. The data in the figures of this report for leeway speed vs. wind speed shows no evidence that there is a change in slope of the regression line. The linearity of the leeway regression vs. $\mathbf{W_{10m}}$ continues down to the lowest wind speed observed, which in most of the data sets in this report are below 2 m/s. The conclusion is that the non-zero leeway speed observed at zero wind speed is the result of shear in the surface water layer that leads to movement of the object relative to the background current. If a particular leeway object had a draft much less or much greater than the depth at which currents are measured the object will in all likelihood have a non-zero speed relative to the defined depth.

5-3 MEAN VALUES OF LEEWAY SPEED VS. REGRESSION MODEL

In a number of cases for which the linear regression was computed for the leeway speed, **DWL**, or **CWL** the coefficient of determination (r^2) was so small, less than 0.20, that the mean value of the independent variable was as good a predictor of the speed as the regression model. (Since in the case of regression constrained through the origin the coefficient of determination has no clear meaning (Section 3-2.2) we will only discuss the unconstrained regression cases.) An r^2 of less than 0.20 occurs in the cases **DWL** for Wharf Box with one and four-person load (Section 4-2.3.2), **CWL** for PIW-I (Section 4-3.1.2), negative **CWL** for PIW-SS (Section 4-3.2.2), and **CWL** for Windsurfer (Section 4-4.2.2). It is noted that in all the cases for very low r^2 the leeway speed involved is a component of leeway speed. In three of the cases the **CWL** component is the one in question. A reference to the data in the relevant section shows that the low r^2 is associated with a very low **CWL** speed at all wind speeds rather than a failure to fit the linear model. In other words in these cases the leeway object in question moves nearly directly downwind. That leaves the case of **DWL** for Wharf Box with one and four-person load. In that case the data for two situations, one and four person loading, were combined. Both cases had distinct, co-linear regression lines that when combined produced a weak regression result.

Experience with leeway has demonstrated that leeway speed and the components of leeway speed are a function of wind speed. The usual behavior of the functionality is for the leeway speed to increase with wind speed with the possible exception of the **CWL** component that may regress to zero (directly downwind) in which case **CWL** will be entirely linear with a nearly zero coefficient of determination. As a matter of standardization we will present all leeway speed in the linear model of equation 3-1.

5-4 RECOMMENDATIONS

5-4.1 Simple Models of Leeway for Manual Search Planning

Two separate versions of simple leeway models are recommended; one for use in manual search planning and another for manual input to "User Defined Leeway" in the present version of CASP. Both simple models are based upon: (1) a constrained linear function of leeway speed on wind speed; (2) an uncertainty of the leeway speed based upon the standard error; (3) twice the standard deviation of the leeway angle about the downwind direction and (4) the mean leeway angle. This model applies when winds are less than 20m/s (40 knots).

Table 5-1. Summary Recommended Manual Leeway Equation Coefficients

(Leeway Speed expressed in cm/s and W_{10m} expressed m/s)

L (cm/s) = Multiplier * W_{10m} (m/s)

L_{max} (cm/s) = Maximum slope * W_{10m} (m/s)

L_{min} (cm/s) = Minimum Slope * W_{10m} (m/s)

Class	Configuration	Multiplier [1]	Speed Uncertainty max./min. slope [2]	Mean Leeway Angle [3]	Divergence max./min. leeway angles [4]
Wharf Box	One-person load	4.07	5.03 3.12	+11°	+29° -7°
Wharf Box	Four-person load	2.52	3.12 1.93	+35°	+53° +17°
Wharf Box	1 & 4-person load	3.00	4.32 1.69	+28°	+56° 0°
PIW	Type I PFD	1.19	1.47 0.92	+4°	+28° -20°
PIW	Survival Suit	2.21	2.77 1.64	+18°	+58° -22°
Sea Kayak	One-person load	3.09	4.35 1.83	+7°	+27° -13°
Windsurfer	W/O mast & sail	3.28	3.88 2.67	-8°	+8° -24°

Notes for Table 5-1.

Note [1] The Multiplier values are based upon the constrained linear regression of leeway speed on $\mathbf{W}_{10m}$.

Note [2] The Speed Uncertainty values are the slopes of the upper and lower lines bounding the regression line. These lines are computed from the 95% prediction limits taken at a $\mathbf{W}_{10m}$ of 10 m/s for the constrained case by adding and subtracting the $\mathbf{W}_{10m}$ value from the regression value at $\mathbf{W}_{10m}$=10 m/s and extending the line through the computed point and the origin.

Note [3] The Mean Leeway Angle is taken from the mean of all leeway drift segments with $\mathbf{W}_{10m}$ above 5 m/s for the leeway object under consideration.

Note [4] The Divergence of the maximum and minimum leeway angles is computed by adding and subtracting twice the standard deviation of the leeway angle to the mean leeway angle for leeway drift segments where $\mathbf{W}_{10m}$ is above 5 m/s..

The recommended manual equation coefficients are presented in Table 5-1 for the PIW, Wharf Box, and personal watercraft drift objects The sources of the computed values in Table 5-1 and Table 5-2 are the data from Chapter 4 and the notes following the tables. The coefficients for manual equations in Table 5-1 are based upon wind speed having units of meters per second and leeway speed having units of centimeters per second. For manual solutions a mean downwind direction and a maximum/minimum leeway angle based upon two standard deviations are recommended for implementation.

Table 5-2 provides recommended coefficients for simple equations that model the leeway of the PIW, Wharf Box, and personal water craft drift objects. These coefficients are presented in the format of CASP "User Defined Leeway" input. For Table 5-2 only, wind speed and leeway speed have units of knots. For a complete discussion of "User Defined Leeway" in CASP, see Allen and Staubs (1997) which is reproduced in Appendix A of Allen and Fitzgerald (1997). In the present version of CASP, User Defined Leeway mean leeway angle is fixed at zero degrees, directly downwind; there is no provision to input a mean leeway angle.

Table 5-2. Summary Recommended CASP "User Defined Leeway" Equation Coefficients (Leeway Speed and W_{10m} are expressed in knots)

Class	Configuration	Multiplier [1]	Speed Uncertainty [2]	Divergence Angle [3]
Wharf Box	One-person load	0.041	0.12	20°
Wharf Box	Four-person load	0.025	0.12	44°
Wharf Box	1 & 4-person load	0.030	0.22	42°
PIW	Type I PFD	0.012	0.12	24°
PIW	Survival Suit	0.022	0.13	38°
Sea Kayak	One-person load	0.031	0.21	20°
Windsurfer	W/O mast & sail	0.033	0.09	16°

Notes for Table 5-2

Note [1] The Multiplier values are based upon the constrained linear regression of leeway speed on $\mathbf{W_{10m}}$ wind speed (Allen and Staubs, 1997).

Note [2] The Speed Uncertainty values are based upon the standard error of estimate, $S_{y/x}$, matched at $\mathbf{W_{10m}}$ = 10.1 m/s (19.6 knots) (Allen and Staubs, 1997).

Note[3] The Divergence Angle is twice the standard deviation of the leeway angle for $\mathbf{W_{10m}}$ greater than 5 m/s (9.7 knots) or the mean plus one standard deviation of the leeway angle; whichever is larger.

5-4.2 Leeway Models for Implementation into Computerized Numerical Search Planning

The model of leeway using the Downwind and Crosswind components of leeway fitted to an unconstrained regression line and bounded by 95% prediction limits is recommended as the model to use when computer analysis is available. Table 5-3 through Table 5-9 list the equations of the mean **DWL** and **CWL** unconstrained regression lines. The bounds on the 95% prediction limits are defined by the coefficients of a pair of second order equations that define the upper limits and lower limits of the 95% prediction zone. Only in the case of the PIW-SS are both positive and negative **CWL** coefficients defined. This

treatment of **CWL** in the PIW-SS case was a result of a bifurcation of CWL values into positive and negative groupings above the wind speed of 5 m/s.

Table 5-3. Summary of the Wharf Box (One Person Loading) Leeway Equations and Coefficients for Numerical Search Models

DWL = Downwind Component of Leeway (cm/s)
CWL = Crosswind Component of Leeway (cm/s)
$\mathbf{W_{10m}}$ = 10 m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(W_{10m})^2 + c_2*(W_{10m}) + c_3$

Wharf Box – One Person Loading						
Mean DWL = 2.53% W_{10m} +9.0 cm/s Mean CWL = 1.09% W_{10m} -2.8 cm/s						
Dependent Variable	Upper Limits			Lower Limits		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.002	2.514	15.065	-0.002	2.548	2.953
CWL	0.002	1.065	5.463	-0.002	1.111	-10.979

Table 5-4. Summary of Wharf Box (Four Person Loading) Leeway Equations and Coefficients for Numerical Search Models

DWL = Downwind Component of Leeway (cm/s)
CWL = Crosswind Component of Leeway (cm/s)
$\mathbf{W_{10m}}$ = 10 m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(W_{10m})^2 + c_2*(W_{10m}) + c_3$

Wharf Box – Four Person Loading						
Mean DWL = 1.15% W_{10m} +7.9 cm/s **Mean CWL = 1.48% W_{10m} –0.3 cm/s**						
Dependent Variable	**Upper Limits**			**Lower Limits**		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.004	1.074	14.503	-0.004	1.223	1.370
CWL	0.004	1.410	5.888	-0.004	1.551	-6.525

Table 5-5. Summary of Wharf Box (One and Four Person Loading) Leeway Equations and Coefficients for Numerical Search Models

DWL = Downwind Component of Leeway (cm/s)
CWL = Crosswind Component of Leeway (cm/s)
$\mathbf{W_{10m}}$ = 10 m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(W_{10m})^2 + c_2*(W_{10m}) + c_3$

Wharf Box – One and Four Person Loading						
Mean DWL = 0.72% W_{10m} +15.2 cm/s **Mean CWL = 1.86% W_{10m} – 5.2 cm/s**						
Dependent Variable	**Upper Limits**			**Lower Limits**		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.001	0.703	26.231	-0.001	0.737	4.125
CWL	0.001	1.847	3.030	-0.001	1.873	-13.552

Table 5-6. **Summary of Person-In-Water (Type I PFD) Leeway Equations and Coefficients for Numerical Search Models**

DWL = Downwind Component of Leeway (cm/s)
CWL = Crosswind Component of Leeway (cm/s)
$\mathbf{W_{10m}}$ = 10 m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(\mathbf{W_{10m}})^2 + c_2*(\mathbf{W_{10m}}) + c_3$

Person-In-Water (Type I PFD)						
Mean DWL = 1.60% W_{10m} – 4.0 cm/s **Mean CWL = 0.13% W_{10m} + 0.3 cm/s**						
Dependent Variable	**Upper Limits**			**Lower Limits**		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.002	1.570	0.913	-0.002	1.629	-8.874
CWL	0.002	0.101	4.601	-0.002	0.152	-3.943

Table 5-7. **Summary of Person-In-Water (Survival Suit) Leeway Equations and Coefficients for Numerical Search Models**

DWL = Downwind Component of Leeway (cm/s)
+CWL = Positive Crosswind Component of Leeway (cm/s)
-CWL = Negative Crosswind Component of Leeway (cm/s)
$\mathbf{W_{10m}}$ = 10 m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(W_{10m})^2 + c_2*(W_{10m}) + c_3$

Person-In-Water (Survival Suit)						
Mean DWL = 1.71% W_{10m} + 1.1 cm/s Mean +CWL = 1.36% W_{10m} – 3.3 cm/s Mean -CWL = - 0.13% W_{10m} – 2.6 cm/s						
Dependent Variable	**Upper Limits**			**Lower Limits**		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.002	1.690	8.903	-0.002	1.727	-6.671
+CWL	0.004	1.284	0.407	-0.004	1.432	-7.003
- CWL	0.052	-0.753	2.711	-0.052	0.500	-8.001

Table 5-8. Summary of Sea Kayak (Person on stern) Leeway Equations and Coefficients for Numerical Search Models

DWL = Downwind Component of Leeway (cm/s)
CWL = Crosswind Component of Leeway (cm/s)
W_{10m} = 10m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(W_{10m})^2 + c_2*(W_{10m}) + c_3$

Sea Kayak (Person on stern)						
Mean DWL = 1.16% W_{10m} + 11.1 cm/s Mean CWL = 0.41% W_{10m} + 0.0 cm/s						
Dependent Variable	**Upper Limits**			**Lower Limits**		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.002	1.144	19.280	-0.002	1.186	2.953
CWL	0.002	0.391	8.690	-0.002	0.435	-8.699

Table 5-9. **Summary of Windsurfer (No Mast or Sail) Leeway Equations and Coefficients for Numerical Search Models**

DWL = Downwind Component of Leeway (cm/s)
CWL = Crosswind Component of Leeway (cm/s)
$\mathbf{W_{10m}}$ = 10 m Wind Speed (m/s)
95% Prediction Limit $\cong c_1*(\mathbf{W_{10m}})^2 + c_2*(\mathbf{W_{10m}}) + c_3$

Windsurfer (No Mast or Sail)						
Mean DWL = 2.25% W_{10m} + 5.0 cm/s Mean CWL = - 0.68% W_{10m} + 1.3 cm/s						
Dependent Variable	Upper Limits			Lower Limits		
	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3	$C_1(W_{10m})^2$	$C_2(W_{10m})$	C_3
DWL	0.002	2.230	9.999	-0.002	2.268	0.054
CWL	0.002	-0.712	7.181	-0.002	-0.667	-4.585

5-5 FUTURE WORK ON THE LEEWAY OF PIWs AND SMALL CRAFT

This report demonstrates that we are now capable of obtaining high quality leeway data on small objects. Since small SAR objects are often the most difficult to detect, accurate prediction of their drift is critical for increased survival of the person(s) in distress. While this is a good start, further efforts are needed.

Leeway data were collected on the five objects when the 10-meter wind speed was 12.2 m/s (23.7) knots or less. Efforts should be made to collect leeway data on the three small craft (Windsurfer, Sea Kayak, and Wharf Box) for wind speeds above 15 m/s and above 20 m/s for the PIWs (PIW with a type I PFD and a PIW in a survival suit).

Leeway determined by the direct methods used in this report should be applied to other configurations of PIWs. The typical orientations of PIWs are vertical (treading water), sitting (survival position), and horizontal (floating on the back or face down in the water), Allen and Plourde (1999). Only conscious PIWs can maintain a vertical position in the water while wearing either a sport/work vest, anti-exposure suit, float coat, or no flotation at all. A conscious or unconscious PIW wearing an offshore lifejacket, a horse-collar lifejacket, or inflatable vest will assume the classic sitting/huddle position in the water. A conscious PIW holding onto a throwable device such as a seat cushion will also assume the sitting position. PIWs in survival suits float on their backs during low to moderate

winds. Victims with no flotation, in sport/work vests, anti-exposure suits, or float coats float facedown in the water. This report provided data for leeway guidance for PIWs in offshore lifejackets in the sitting position and for PIWs in survival suits in the horizontal position. Leeway data using the direct method should be collected on the other configurations of PIWs.

Future measurements of leeway are also required for other small craft. There are no leeway data for rowboats of any kind. There are no leeway data for personal watercraft. As with the case of the commercial fisherman and his wharf box, the sport fisherman will use a large ice chest/cooler (typically 96 quarts) to provide survival flotation and for which no leeway data exists. Other objects associated with SAR cases for which there is no leeway data include (1) seat cushions, (2) distress beacons, (3) aviation debris – aircraft wreckage, aircraft seats, and luggage.

Other no-SAR objects for which leeway data should be collected using the methods and instrumentation used in this work include: bales of contraband, 55-gallon drums, cargo containers, disabled barges, tankers or freighters and tree trunks.

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APPENDIX A

LEEWAY DATA, JANUARY/FEBRUARY 1998

Data Description

Column 1:

Decimal Days – Julian date or Yearday for example January 18th at midnight is 18.000, etc.

Column 2:

Wind Speed at 10m (m/s) – Wind speed adjusted from the observation level to a standard 10 m reference level.

Column 3:

Wind Direction (° True) – Wind Direction related to True North using the convention of "wind toward".

Column 4:

Target Speed (cm/s) - Speed of the leeway object that is attributed to leeway. Output of the onboard current meter.

Column 5:

Target Direction (° True) – Leeway object drift direction related to True North as measured by the onboard current meter using the "current toward" convention.

A-1 Wharf Box Leeway Runs 114, 117, 127, and 128

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
18.774	10.5	182	38.3	185
18.781	10.7	184	38.8	188
18.788	10.6	182	37.4	186
18.795	10.5	178	37.9	185
18.802	10.4	175	37.0	180
18.809	10.2	174	36.2	174
18.816	9.7	175	34.6	176
18.823	10.4	170	37.7	177
18.830	10.3	171	36.9	173
18.837	10.6	172	37.4	175
18.844	10.3	166	37.4	173
18.851	10.8	162	39.3	170
18.858	11.2	161	39.7	167
18.865	10.7	164	34.9	175
18.872	10.6	169	36.7	175
18.879	10.8	172	38.3	178
18.885	10.4	173	35.0	178
18.892	10.1	173	35.5	177
18.899	9.8	180	32.5	187
18.906	9.3	181	32.0	183
18.913	9.3	184	32.5	189
18.920	9.3	182	31.7	188
18.927	8.4	178	30.7	182
18.934	8.8	181	31.3	188
18.941	8.6	179	29.5	182
18.948	8.3	181	27.3	188
18.955	8.6	177	30.0	183
18.962	8.3	177	28.6	181
18.969	8.1	174	29.6	183
18.976	8.0	178	29.1	180
18.983	8.2	183	28.1	188
18.990	7.9	177	28.4	179
18.997	6.1	176	28.4	183
19.004	4.3	177	28.1	184
19.010	4.4	179	27.8	178
19.017	4.3	185	26.9	188
19.024	4.1	177	27.9	180
19.031	3.6	184	25.4	183
19.038	3.3	186	22.9	184
19.045	3.9	180	25.4	182
19.052	3.8	186	26.1	187
19.059	4.0	179	26.8	183
19.066	3.8	183	25.4	185
19.073	3.7	183	26.2	186
19.080	3.9	182	26.0	185
19.087	3.7	191	26.4	191
19.094	3.6	191	25.8	193
19.101	3.3	189	23.7	198
19.108	3.3	192	24.4	190
19.115	3.5	194	24.6	192
19.122	3.7	186	24.7	188
19.129	3.6	186	24.9	188
19.135	3.3	191	25.1	188
19.142	3.7	181	24.4	178

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
19.149	3.7	182	20.8	194
19.156	3.2	183	23.4	195
19.163	3.6	178	23.4	189
19.170	3.8	184	24.9	187
19.177	3.6	180	23.4	185
19.184	3.8	182	24.6	185
19.191	3.5	185	23.6	185
19.198	3.4	184	23.9	188
19.205	4.9	190	27.0	190
19.212	4.9	178	27.5	184
19.219	5.0	186	28.9	189
19.226	4.9	185	28.2	190
19.233	4.2	186	26.1	189
19.240	3.3	180	22.7	187
19.247	3.5	142	21.3	176
19.254	4.3	136	22.5	166
19.260	3.6	137	21.0	164
19.267	4.8	146	25.6	174
19.274	5.9	133	28.5	164
19.281	5.3	147	27.0	175
19.288	4.9	149	25.2	178
19.295	4.8	146	24.7	174
19.302	4.7	158	25.7	181
19.309	4.5	157	23.4	185
19.316	4.3	153	22.4	184
19.323	3.3	164	20.1	183
19.330	3.4	166	20.5	189
19.337	3.3	146	20.8	175
19.344	2.8	157	18.7	183
19.351	3.3	155	18.1	177
19.358	3.2	166	20.5	182
19.365	4.2	156	22.7	181
19.372	4.2	162	23.4	185
19.379	4.2	168	23.2	191
19.385	4.2	173	23.0	195
19.392	4.2	178	22.3	197
19.399	3.5	180	18.4	193
19.406	3.7	159	21.6	192
19.413	3.7	158	21.1	187
19.420	4.4	152	23.1	188
19.427	4.3	152	23.1	189
19.434	3.9	153	21.6	184
19.441	3.7	158	21.6	190
19.448	4.2	155	22.3	186
19.455	3.9	170	19.4	190
19.462	3.8	172	20.3	198
19.469	3.4	204	19.9	203
19.476	3.4	205	20.3	199
21.767	4.7	159	24.8	160
21.774	5.7	160	25.3	158
21.781	4.7	159	22.4	161
21.788	5.2	145	23.2	150
21.795	5.5	136	25.3	142
21.802	4.5	147	19.0	145
21.809	5.1	154	22.9	154
21.816	4.7	148	21.4	149
21.823	4.9	149	23.4	156
21.830	4.9	141	23.3	148

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
21.837	4.9	137	22.2	142
21.844	5.1	119	22.1	131
21.851	4.9	123	21.5	135
21.858	5.2	121	23.2	132
21.865	5.2	134	22.2	139
21.872	4.8	132	21.3	136
21.879	4.7	136	22.4	141
21.885	5.6	137	22.2	136
21.892	5.4	133	22.3	138
21.899	5.3	132	22.4	136
21.906	5.0	144	19.1	148
21.913	4.8	136	22.3	143
21.920	4.7	137	21.3	138
21.927	4.6	133	20.4	137
21.934	4.9	139	19.6	135
21.941	4.9	136	17.1	142
21.948	5.2	141	21.1	151
21.955	5.8	134	24.2	145
21.962	5.7	136	23.6	141
21.969	5.9	132	23.4	136
21.976	6.9	136	27.0	142
21.983	7.7	132	29.5	138
21.990	8.0	129	31.3	136
21.997	7.2	132	27.7	138
22.004	6.5	131	27.4	137
22.010	6.7	139	28.7	142
22.017	6.8	137	26.7	141
22.024	6.5	137	28.3	145
22.031	6.8	135	26.9	138
22.038	6.8	135	25.4	139
22.045	6.4	135	25.3	139
22.052	6.0	141	26.5	148
22.059	5.7	145	23.7	144
22.066	5.9	139	24.5	144
22.073	5.5	134	24.2	141
22.080	6.1	137	26.4	143
22.087	5.5	141	24.5	145
22.094	6.1	144	25.8	146
22.101	6.1	141	25.5	144
22.108	5.8	143	24.0	142
22.115	5.6	151	24.4	152
22.122	4.9	144	20.9	141
22.129	4.9	138	21.3	138
22.135	4.4	131	20.0	137
22.142	4.6	135	21.2	140
22.149	5.0	145	23.4	149
22.156	5.1	138	22.8	146
22.163	5.6	143	23.9	147
22.170	5.7	137	24.2	140
22.177	5.4	145	23.5	146
22.184	4.2	133	20.1	141
22.191	4.2	136	19.5	141
22.198	4.0	135	18.5	138
22.205	4.2	145	19.8	145
22.212	4.1	129	20.7	137
22.219	4.1	145	18.3	140
22.226	3.5	135	13.8	141
22.233	3.2	124	16.0	137

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.240	2.9	126	16.4	139
22.247	3.1	133	16.5	136
22.254	3.0	132	15.4	135
22.260	2.9	133	16.7	138
22.267	2.7	126	13.0	127
22.274	3.3	132	15.1	130
22.281	4.0	134	18.8	134
22.288	3.6	131	18.8	140
22.295	4.4	140	20.1	141
22.302	4.2	135	19.1	138
22.309	3.5	135	14.4	140
22.316	3.9	143	16.7	150
22.323	4.2	136	19.6	139
22.330	4.3	151	17.0	146
22.337	4.2	151	19.8	149
22.344	4.7	144	21.9	142
22.351	4.3	153	19.5	147
22.358	4.7	153	21.8	147
22.365	4.8	146	21.0	144
22.372	4.4	150	21.1	148
22.379	4.6	150	20.4	145
22.385	4.5	156	18.4	151
22.392	4.6	169	18.4	160
22.399	4.4	161	20.7	154
22.406	4.8	158	19.6	155
22.413	4.3	159	17.5	164
22.420	4.7	164	21.9	162
22.427	4.4	163	20.4	162
22.434	3.9	170	19.4	163
22.441	4.3	160	20.5	157
22.448	4.5	157	18.8	154
22.455	4.1	166	16.8	167
22.462	4.3	170	20.8	169
22.469	4.1	168	19.8	163
22.476	3.4	168	14.3	166
22.483	2.4	181	15.2	169
22.490	2.6	184	13.9	164
22.497	3.3	182	13.0	168
22.504	3.2	179	12.0	172
22.510	3.1	160	15.6	170
22.517	3.4	187	17.3	174
22.524	3.2	171	16.6	167
22.531	2.7	182	13.8	167
22.538	3.0	180	15.0	167
22.545	2.9	185	14.0	165
22.552	2.6	184	13.0	168
22.559	2.9	183	13.1	167
22.566	3.1	170	14.5	161
22.573	2.6	181	12.6	165
22.580	2.2	193	9.3	170
22.587	2.5	187	14.3	178
22.594	2.2	188	13.4	173
22.601	2.3	189	12.9	176
22.608	2.7	188	13.6	173
22.615	2.6	174	13.2	164
22.622	2.4	179	12.5	164
22.629	2.3	192	11.6	171
22.635	2.2	211	7.8	187

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.642	2.1	197	11.6	191
22.649	2.2	179	13.1	171
22.656	2.4	168	12.3	164
22.663	2.0	196	11.1	172
22.670	2.8	174	14.4	171
22.677	2.6	193	13.2	182
22.684	2.0	219	11.0	190
22.691	2.4	202	12.2	183
22.698	2.1	187	10.9	172
22.705	2.2	205	10.5	179
22.712	2.0	196	9.6	177
22.719	2.9	182	10.3	185
22.726	2.7	209	13.7	198
22.733	2.0	215	11.4	195
22.740	2.8	209	13.2	195
22.747	2.8	199	12.4	190
22.754	2.1	219	8.3	200
22.760	2.8	220	14.0	218
22.767	2.7	229	13.4	212
22.774	2.5	232	12.2	210
22.781	2.6	225	9.3	215
22.788	2.7	224	12.9	232
22.795	3.2	236	15.9	226
22.802	3.1	229	12.1	217
22.809	2.8	235	11.0	236
22.816	2.3	241	13.4	230
22.823	2.6	256	12.8	230
22.830	3.0	242	11.6	228
22.837	3.8	240	14.6	256
22.844	3.5	236	16.7	255
22.851	3.7	249	16.5	243
22.858	3.3	243	13.6	253
22.865	3.7	250	18.1	259
22.872	3.6	245	18.8	245
22.879	3.5	250	18.1	248
22.885	3.4	252	16.1	248
22.892	3.4	242	17.1	243
22.899	3.8	249	17.7	248
22.906	4.3	245	20.8	251
22.913	4.4	242	21.1	251
22.920	4.2	254	18.3	254
22.927	4.1	254	19.2	259
22.934	4.0	249	20.3	259
22.941	3.8	256	17.5	266
22.948	5.1	258	24.2	275
22.955	5.1	261	22.9	277
22.962	5.6	258	25.2	275
22.969	6.0	251	27.0	271
22.976	5.9	252	26.4	269
22.983	6.5	251	27.6	273
22.990	6.6	252	27.7	272
22.997	6.9	249	28.4	270
23.004	7.1	249	27.4	267
23.010	7.3	243	28.6	267
23.017	7.6	248	28.7	266
23.024	7.5	246	29.2	267
23.031	8.3	243	31.0	268
23.038	8.6	248	31.3	270

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
23.045	8.6	247	32.0	268
23.052	9.0	246	32.2	266
23.059	9.0	246	32.6	266
23.066	9.1	249	32.0	268
23.073	8.9	246	32.2	264
23.080	8.8	247	31.1	268
23.087	9.0	248	31.5	265
23.094	9.1	248	32.6	267
23.101	9.3	248	32.7	269
23.108	9.6	251	34.7	273
23.115	9.9	252	33.9	278
23.122	9.8	250	33.4	272
23.129	10.0	250	33.7	275
23.135	10.0	249	33.4	273
23.142	10.1	248	33.7	270
23.149	10.4	248	34.6	271
23.156	10.5	247	35.7	272
23.163	9.9	249	34.6	270
23.170	10.0	248	34.4	268
23.177	9.8	248	32.3	271
23.184	9.8	248	33.2	271
23.191	9.0	248	31.0	272
23.198	8.3	249	30.4	268
23.205	8.5	249	30.8	268
23.212	7.6	252	27.9	272
23.219	7.4	260	26.0	282
23.226	7.3	272	24.8	289
23.233	7.7	276	27.3	297
23.240	7.8	279	26.1	299
23.247	8.1	280	26.7	300
30.385	7.2	28	15.8	50
30.392	7.3	24	20.1	56
30.399	7.6	27	19.7	60
30.406	7.4	32	18.6	62
30.413	7.4	37	18.7	61
30.420	7.5	38	20.1	61
30.427	7.4	46	20.1	64
30.434	7.5	49	20.1	67
30.441	7.4	58	20.3	78
30.448	7.2	70	21.8	83
30.455	7.3	64	19.0	90
30.462	7.3	73	19.4	91
30.469	6.8	73	18.5	96
30.476	7.0	77	19.6	94
30.483	7.4	81	21.0	92
30.490	7.3	79	21.2	100
30.497	7.1	79	21.1	98
30.504	7.2	80	18.8	100
30.510	6.9	82	19.6	104
30.517	6.6	89	19.8	103
30.524	6.2	89	20.4	105
30.531	6.4	104	21.1	108
30.538	6.2	109	19.2	119
30.545	6.1	103	19.4	123
30.552	5.8	109	19.8	119
30.559	6.0	113	20.2	121
30.566	5.8	109	20.3	126
30.573	5.6	113	20.7	128

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
30.580	5.8	111	19.2	127
30.587	5.5	121	18.8	126
30.594	5.1	119	19.6	131
30.601	4.6	130	18.3	130
30.608	4.8	128	18.4	127
30.615	6.1	133	21.6	136
30.622	6.7	133	21.6	133
30.629	6.7	133	25.1	131
30.635	7.4	135	23.5	146
30.642	8.6	142	26.0	148
30.649	8.5	128	27.6	158
30.656	8.6	128	28.6	160
30.663	8.3	129	29.0	159
30.670	8.4	129	28.7	162
30.677	8.0	131	28.8	160
30.684	7.8	129	28.5	160
30.691	8.0	128	28.8	163
30.698	8.0	130	28.0	160
30.705	7.9	135	29.0	159
30.712	8.0	132	27.9	170
30.719	8.0	131	27.5	165
30.726	7.8	134	27.8	167
30.733	7.9	134	26.8	174
30.740	7.8	139	25.8	170
30.747	7.7	133	26.0	172
30.754	7.8	129	25.3	167
30.760	7.6	126	26.1	168
30.767	8.2	128	27.6	168
30.774	8.3	123	27.2	158
30.781	8.9	122	30.2	158
30.788	9.1	121	29.1	157
30.795	8.7	124	26.0	157
30.802	9.3	124	27.5	156
30.809	9.2	119	28.3	156
30.816	9.6	121	28.5	163
30.823	9.8	118	29.0	156
30.830	10.3	120	29.5	158
30.837	10.2	122	27.7	160
30.844	10.4	120	27.1	157
30.851	10.3	120	28.9	159
30.858	9.9	122	27.2	163
30.865	10.1	123	27.0	164
30.872	10.2	122	28.8	162
30.879	10.2	122	29.2	158
30.885	10.3	121	29.8	158
30.892	9.8	125	27.4	168
30.899	9.9	125	27.4	161
30.906	9.8	125	27.9	156
30.913	9.9	123	27.3	156
30.920	10.1	127	29.0	163
30.927	9.5	124	25.5	162
30.934	9.5	123	25.3	160
30.941	9.9	123	28.4	160
30.948	9.9	123	27.5	158
30.955	10.5	122	28.2	157
30.962	10.3	126	28.1	157
30.969	10.2	122	28.2	158
30.976	10.3	120	27.8	160

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
30.983	10.3	123	26.9	158
30.990	10.8	124	29.0	163
30.997	10.4	123	27.1	167
31.004	11.2	125	27.6	166
31.010	11.8	127	25.3	170
31.017	11.6	125	26.5	160
31.024	11.8	127	28.4	163
31.031	12.2	124	27.8	161
31.038	11.8	128	27.7	167
31.045	11.6	129	26.9	164
31.129	11.2	131	26.2	167
31.135	11.6	133	26.4	166
31.142	11.8	130	27.6	165
31.149	11.5	134	27.0	174
31.156	11.2	132	25.4	166
31.163	11.1	135	25.5	171
31.170	11.4	135	25.7	169
31.177	11.4	132	26.1	173
31.184	11.7	132	25.9	166
31.191	11.6	135	26.7	171
31.198	11.3	153	24.0	159
31.205	10.4	141	24.4	161
31.212	10.8	131	24.6	169
31.219	10.5	130	24.4	165
31.226	10.9	130	24.5	165
31.233	10.7	131	23.6	169
31.240	10.2	129	22.4	171
31.247	10.4	130	23.9	170
31.254	10.9	131	25.5	164
31.260	10.8	134	24.9	174
31.267	10.7	133	25.4	170
31.274	11.4	141	26.6	174
31.281	11.6	162	26.9	168
31.288	11.2	157	26.9	170
31.295	10.9	136	25.9	165
31.302	10.8	141	25.8	175
31.309	11.0	139	25.2	174
31.316	10.5	138	23.1	178
31.323	10.5	138	24.3	175
31.330	11.0	136	25.9	171
31.337	11.5	136	25.8	168
31.344	10.5	141	23.9	177
31.351	9.9	143	23.0	174
31.358	10.4	139	24.2	174
31.365	9.9	154	23.7	174
31.372	9.6	143	21.9	176
31.379	9.0	142	21.6	175
31.385	9.6	142	22.8	185
31.392	10.2	149	24.9	179
31.399	9.9	151	22.7	184
31.406	10.0	150	24.4	183
31.413	9.8	148	22.4	192
31.420	9.8	149	23.4	190
31.427	9.3	147	22.8	182
31.434	9.6	147	22.1	184
31.441	9.6	152	23.2	186
31.448	9.4	146	21.7	181
31.455	9.0	146	21.8	179

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
31.462	9.7	150	22.4	191
31.469	9.4	142	22.8	182
31.476	9.1	146	22.1	183
31.483	8.9	145	20.6	184
31.490	9.1	141	21.9	188
31.497	9.1	145	22.3	183
31.504	9.4	153	22.0	185
31.510	8.8	152	21.9	188
31.517	9.4	147	23.1	181
31.524	9.7	149	22.4	190
31.531	9.2	150	23.2	192
31.538	9.5	150	23.2	186
31.545	9.2	153	21.6	191
31.552	9.3	156	22.6	194
31.559	9.3	154	20.7	186
31.566	9.0	153	20.4	190
31.573	9.2	153	21.7	188
31.580	9.5	149	22.0	189
31.587	9.5	149	22.8	190
31.594	9.5	151	22.2	194
31.601	9.8	149	23.2	192
31.608	10.0	152	24.2	192
31.615	10.5	150	25.2	185
31.622	10.2	151	24.2	189
31.629	10.4	153	24.0	192
31.635	10.5	151	24.0	185
31.642	10.5	157	24.4	193
31.649	10.4	158	23.8	194
31.656	10.4	154	24.6	192
31.663	10.1	155	23.0	192
31.670	10.1	155	24.2	189
31.677	10.2	157	23.4	193
31.684	9.6	163	21.1	197
31.691	9.6	160	22.8	192
31.698	9.3	158	21.4	200
31.705	9.2	161	21.4	200
31.712	9.1	158	21.6	194
31.719	9.3	159	21.8	204
31.726	9.0	152	21.5	197
31.733	9.5	159	21.8	199
31.740	9.1	154	20.6	193
31.747	9.6	156	22.3	197
31.754	9.4	159	21.6	201
31.760	9.8	158	22.2	193
31.767	9.3	162	22.9	197
31.774	9.6	163	21.4	200
31.781	9.4	160	22.4	196
31.788	9.4	156	23.1	198
31.795	9.1	156	21.2	196
31.802	9.2	153	20.4	191
31.809	8.9	163	22.1	202
31.816	9.2	157	20.0	193
31.823	8.3	154	20.2	193
31.830	8.9	151	21.8	193
31.837	8.8	152	21.8	195
31.844	8.9	155	21.4	193
31.851	8.2	152	20.8	195
31.858	8.8	152	20.7	198

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
31.865	8.1	147	19.2	193
31.872	8.2	154	19.4	195
31.879	8.0	152	19.4	192
31.885	7.9	145	19.6	193
31.892	8.2	146	19.6	191
31.899	8.3	154	20.7	188
31.906	8.2	156	19.7	197
31.913	8.0	150	19.4	190
31.920	8.4	148	19.4	195
31.927	8.2	144	20.1	186
31.934	8.7	144	21.1	182
31.941	8.1	142	17.5	186
31.948	7.7	139	18.7	187
31.955	7.8	147	19.6	190
31.962	7.6	139	17.7	183
31.969	7.6	147	17.6	191
31.976	7.8	149	18.2	191
31.983	8.1	144	19.1	187
31.990	8.0	145	20.4	184
31.997	8.0	143	20.4	190
32.004	8.6	149	19.7	203
32.010	8.8	156	19.8	195
32.017	9.1	157	19.1	197
32.024	8.1	163	18.5	212
32.031	8.4	180	19.3	216
32.038	7.9	172	18.5	206
32.045	8.7	171	19.7	210
32.052	7.7	168	17.4	208
32.059	7.9	164	19.4	200
32.066	8.3	157	19.2	204
32.073	8.3	154	18.7	198
32.080	8.5	162	19.1	203
32.087	8.5	161	18.1	197
32.094	8.4	161	19.5	199
32.101	9.2	161	19.6	204
32.108	8.8	160	19.6	193
32.115	8.6	155	19.8	195
32.122	8.4	160	18.7	199
32.129	8.2	159	19.1	199
32.135	8.6	161	19.1	197
32.142	8.8	162	19.3	203
32.149	8.4	165	19.1	199
32.156	8.5	162	18.8	204
32.163	7.8	166	18.3	203
32.170	7.9	158	18.8	200
32.177	7.5	163	17.7	204
32.184	7.2	160	17.5	199
32.191	7.7	160	17.0	201
32.198	7.7	179	16.1	211
32.205	7.1	180	17.4	223
32.212	6.2	176	16.2	214
32.219	6.6	172	16.5	215
32.226	7.0	170	16.6	206
32.233	7.0	173	18.1	216
32.240	6.7	168	16.9	204
32.247	6.9	177	15.8	219
32.254	6.9	166	17.0	212
32.260	6.9	164	18.0	207

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
32.267	7.1	163	17.8	210
32.274	7.2	160	18.2	210
32.281	6.8	165	17.4	210
32.288	7.5	174	18.0	212
32.295	6.5	181	17.2	219
32.302	7.0	187	17.7	222
32.309	7.2	174	17.4	214
32.316	7.1	171	18.5	206
32.323	7.1	167	16.7	217
32.330	7.3	177	18.7	212
32.337	7.8	172	17.8	212
32.344	8.1	180	18.8	222
32.351	7.4	170	18.8	204
32.358	8.0	176	20.0	219
32.365	7.6	172	18.4	214
32.372	8.2	176	19.1	220
32.379	7.7	171	18.5	213
32.385	7.4	174	19.0	218
32.392	7.8	178	19.3	223
32.399	7.3	173	18.4	210
32.406	7.7	181	19.4	222
32.413	7.4	176	17.1	213
32.420	6.9	188	18.2	224
32.427	6.5	176	16.9	220
32.434	7.2	171	18.8	219
32.441	6.7	182	18.2	219
32.448	6.2	183	17.5	227
32.455	7.0	183	17.5	224
32.462	6.3	182	17.6	223
32.476	7.0	181	18.3	224
32.483	6.9	177	18.4	215
32.490	6.5	172	18.3	221
32.497	6.6	170	18.0	217
32.504	6.6	175	17.9	215
32.510	6.5	174	17.5	218
32.517	6.5	187	16.8	233
32.524	7.5	169	19.8	214

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Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
26.837	2.2	163	2.0	62
26.844	2.7	174	2.8	40
26.851	2.1	169	2.7	75
26.858	2.1	175	3.4	47
26.865	3.1	173	3.1	21
26.872	3.4	174	3.4	350
26.879	3.6	189	2.7	282
26.885	3.1	195	2.3	8
26.892	3.7	175	3.4	29
26.899	3.7	193	2.5	318
26.906	3.9	194	3.3	324

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
26.913	3.7	200	3.6	313
26.920	3.5	206	4.9	268
26.927	2.8	196	4.2	312
26.934	3.2	204	2.7	353
26.941	3.3	203	3.6	37
26.948	3.6	210	2.8	326
26.955	3.1	213	3.2	293
26.962	2.9	222	2.2	342
26.969	3.3	214	2.7	303
26.976	3.6	218	3.6	301
26.983	3.2	218	3.4	267
26.990	3.2	222	3.4	299
26.997	2.9	247	3.6	237
27.004	3.1	255	2.6	338
27.010	3.1	253	3.2	283
27.017	3.2	255	2.6	293
27.024	3.1	254	3.6	317
27.031	3.6	254	3.7	264
27.038	3.3	243	3.3	298
27.045	3.7	248	3.7	312
27.052	3.6	261	2.8	284
27.059	4.0	266	2.9	333
27.066	4.3	247	3.2	298
27.073	4.0	261	4.0	281
27.080	4.0	262	5.2	284
27.087	4.4	261	4.2	336
27.094	3.9	260	4.8	321
27.101	3.9	271	3.7	327
27.108	4.0	273	3.5	9
27.115	4.0	271	2.6	16
27.122	3.7	260	3.4	353
27.129	4.0	251	3.5	36
27.135	3.9	257	2.7	7
27.142	4.7	260	2.8	345
27.149	4.4	272	4.7	25
27.156	4.2	275	5.1	22
27.163	4.3	269	3.9	16
30.385	7.2	28	10.3	28
30.392	7.3	24	10.9	38
30.399	7.6	27	10.4	43
30.406	7.4	32	10.4	44
30.413	7.4	37	11.3	41
30.420	7.5	38	9.8	45
30.427	7.4	46	10.7	43
30.434	7.5	49	10.8	43
30.441	7.4	58	10.5	54
30.448	7.2	70	10.5	55
30.455	7.3	64	10.2	52
30.462	7.3	73	10.6	61
30.469	6.8	73	10.2	61
30.476	7.0	77	10.5	63
30.483	7.4	81	10.4	65
30.490	7.3	79	10.4	73
30.497	7.1	79	10.6	73
30.504	7.2	80	9.2	75
30.510	6.9	82	9.8	77
30.517	6.6	89	9.4	83
30.524	6.2	89	9.9	79

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
30.531	6.4	104	9.5	88
30.538	6.2	109	9.1	85
30.545	6.1	103	9.7	90
30.552	5.8	109	9.2	97
30.559	6.0	113	9.4	98
30.566	5.8	109	10.1	105
30.573	5.6	113	9.2	104
30.580	5.8	111	9.4	103
30.587	5.5	121	8.8	109
30.594	5.1	119	8.0	104
30.601	4.6	130	7.3	110
30.608	4.8	128	7.9	107
30.615	6.1	133	8.3	118
30.622	6.7	133	8.8	115
30.629	6.7	133	8.9	112
30.635	7.4	135	10.4	124
30.642	8.6	142	11.0	131
30.649	8.5	128	10.5	145
30.656	8.6	128	10.6	143
30.663	8.3	129	10.4	144
30.670	8.4	129	9.8	149
30.677	8.0	131	11.0	140
30.684	7.8	129	10.2	132
30.691	8.0	128	10.5	139
30.698	8.0	130	9.2	143
30.705	7.9	135	8.5	142
30.712	8.0	132	9.3	142
30.719	8.0	131	10.4	145
30.726	7.8	134	10.0	148
30.733	7.9	134	9.5	147
30.740	7.8	139	8.9	142
30.747	7.7	133	10.7	144
30.754	7.8	129	10.4	143
30.760	7.6	126	10.5	135
30.767	8.2	128	10.5	141
30.774	8.3	123	10.9	132
30.781	8.9	122	11.2	129
30.788	9.1	121	10.0	137
30.795	8.7	124	10.4	134
30.802	9.3	124	11.1	134
30.809	9.2	119	10.2	131
30.816	9.6	121	12.0	129
30.823	9.8	118	10.9	136
30.830	10.3	120	10.6	134
30.837	10.2	122	10.8	138
30.844	10.4	120	11.7	132
30.851	10.3	120	11.0	132
30.858	9.9	122	10.8	133
30.865	10.1	123	10.4	133
30.872	10.2	122	10.3	129
30.879	10.2	122	10.9	131
30.885	10.3	121	11.4	138
30.892	9.8	125	11.1	133
30.899	9.9	125	11.1	139
30.906	9.8	125	10.3	132
30.913	9.9	123	10.3	124
30.920	10.1	127	10.9	138
30.927	9.5	124	11.9	133

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
30.934	9.5	123	11.3	136
30.941	9.9	123	10.4	134
30.948	9.9	123	12.0	137
30.955	10.5	122	12.1	139
30.962	10.3	126	12.1	146
30.969	10.2	122	12.5	139
30.976	10.3	120	12.0	135
30.983	10.3	123	10.2	129
30.990	10.8	124	11.2	134
30.997	10.4	123	13.3	129
31.004	11.2	125	11.6	134
31.010	11.8	127	11.9	142
31.017	11.6	125	12.0	140
31.024	11.8	127	12.5	137
31.031	12.2	124	12.5	145
31.038	11.8	128	12.2	141
31.045	11.6	129	11.7	146

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Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
21.781	4.7	159	9.9	137
21.788	5.2	145	10.7	129
21.795	5.5	136	11.6	119
21.802	4.5	147	10.8	126
21.809	5.1	154	11.0	132
21.816	4.7	148	9.8	124
21.823	4.9	149	10.7	129
21.830	4.9	141	10.1	119
21.837	4.9	137	9.7	118
21.844	5.1	119	11.2	110
21.851	4.9	123	11.1	108
21.858	5.2	121	11.8	107
21.865	5.2	134	10.5	111
21.872	4.8	132	11.2	109
21.879	4.7	136	11.9	107
21.885	5.6	137	13.3	117
21.892	5.4	133	13.0	111
21.899	5.3	132	11.3	114
21.906	5.0	144	11.5	115
21.913	4.8	136	11.1	115
21.920	4.7	137	10.7	117
21.927	4.6	133	9.4	114
21.934	4.9	139	10.9	113
21.941	4.9	136	11.5	120
21.948	5.2	141	12.2	118
21.955	5.8	134	12.9	110
21.962	5.7	136	12.7	120
21.969	5.9	132	12.6	119
21.976	6.9	136	12.8	117
21.983	7.7	132	15.5	118
21.990	8.0	129	15.2	117

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
21.997	7.2	132	14.8	108
22.004	6.5	131	14.5	112
22.010	6.7	139	14.5	126
22.017	6.8	137	13.8	124
22.024	6.5	137	12.5	125
22.031	6.8	135	13.2	123
22.038	6.8	135	14.4	129
22.045	6.4	135	14.3	119
22.052	6.0	141	13.0	129
22.059	5.7	145	11.6	127
22.066	5.9	139	12.4	121
22.073	5.5	134	12.2	129
22.080	6.1	137	12.4	127
22.087	5.5	141	13.3	125
22.094	6.1	144	11.6	134
22.101	6.1	141	12.7	128
22.108	5.8	143	12.6	125
22.115	5.6	151	11.1	127
22.122	4.9	144	10.8	123
22.129	4.9	138	10.4	121
22.135	4.4	131	10.8	124
22.142	4.6	135	11.9	121
22.149	5.0	145	11.2	127
22.156	5.1	138	10.6	121
22.163	5.6	143	12.8	125
22.170	5.7	137	11.6	129
22.177	5.4	145	10.6	122
22.184	4.2	133	10.3	120
22.191	4.2	136	10.2	120
22.198	4.0	135	9.4	125
22.205	4.2	145	10.2	125
22.212	4.1	129	9.4	114
22.219	4.1	145	9.9	125
22.226	3.5	135	9.0	125
22.233	3.2	124	9.9	109
22.240	2.9	126	8.6	113
22.247	3.1	133	9.3	111
22.254	3.0	132	9.5	118
22.260	2.9	133	8.9	124
22.267	2.7	126	9.4	118
22.274	3.3	132	9.0	122
22.281	4.0	134	10.9	114
22.288	3.6	131	11.2	124
22.295	4.4	140	11.1	125
22.302	4.2	135	9.7	120
22.309	3.5	135	9.1	116
22.316	3.9	143	10.1	114
22.323	4.2	136	10.3	124
22.330	4.3	151	11.1	122
22.337	4.2	151	11.1	134
22.344	4.7	144	12.7	136
22.351	4.3	153	12.2	133
22.358	4.7	153	12.3	133
22.365	4.8	146	11.3	127
22.372	4.4	150	11.1	128
22.379	4.6	150	11.4	136
22.385	4.5	156	10.1	127
22.392	4.6	169	10.1	134

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.399	4.4	161	10.8	139
22.406	4.8	158	12.0	134
22.413	4.3	159	10.8	142
22.420	4.7	164	10.9	144
22.427	4.4	163	10.8	145
22.434	3.9	170	10.8	144
22.441	4.3	160	11.2	143
22.448	4.5	157	10.8	147
22.455	4.1	166	10.0	153
22.462	4.3	170	9.7	153
22.469	4.1	168	9.6	154
22.476	3.4	168	8.1	153
22.483	2.4	181	8.3	160
22.490	2.6	184	8.2	165
22.497	3.3	182	8.8	132
22.504	3.2	179	7.6	102
22.510	3.1	160	8.3	162
22.517	3.4	187	9.3	127
22.524	3.2	171	8.8	132
22.531	2.7	182	8.4	42
22.538	3.0	180	8.0	141
22.545	2.9	185	8.0	43
22.552	2.6	184	8.0	104
22.559	2.9	183	8.4	133
22.566	3.1	170	8.9	134
22.573	2.6	181	7.6	42
22.580	2.2	193	9.5	289
22.587	2.5	187	7.4	318
22.594	2.2	188	7.7	105
22.601	2.3	189	8.9	165
22.608	2.7	188	8.1	101
22.615	2.6	174	7.3	75
22.622	2.4	179	8.8	77
22.629	2.3	192	9.4	44
22.635	2.2	211	8.1	292
22.642	2.1	197	9.6	351
22.649	2.2	179	9.7	254
22.656	2.4	168	7.2	132
22.663	2.0	196	7.0	130
22.670	2.8	174	8.9	258
22.677	2.6	193	6.9	317
22.684	2.0	219	9.2	210
22.691	2.4	202	8.8	205
22.698	2.1	187	8.6	325
22.705	2.2	205	7.2	11
22.712	2.0	196	8.0	315
22.719	2.9	182	9.4	262
22.726	2.7	209	9.6	204
22.733	2.0	215	10.9	212
22.740	2.8	209	11.3	218
22.747	2.8	199	10.8	216
22.754	2.1	219	10.5	218
22.760	2.8	220	9.6	224
22.767	2.7	229	11.2	230
22.774	2.5	232	10.7	232
22.781	2.6	225	12.3	228
22.788	2.7	224	11.0	229
22.795	3.2	236	10.1	236

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.802	3.1	229	12.1	242
22.809	2.8	235	11.2	245
22.816	2.3	241	9.6	248
22.823	2.6	256	9.8	251
22.830	3.0	242	11.0	250
22.837	3.8	240	12.0	255
22.844	3.5	236	11.4	254
22.851	3.7	249	12.0	257
22.858	3.3	243	9.2	266
22.865	3.7	250	11.2	263
22.872	3.6	245	11.7	269
22.879	3.5	250	11.6	273
22.885	3.4	252	10.5	278
22.892	3.4	242	9.3	281
22.899	3.8	249	7.0	272
22.906	4.3	245	9.4	276
22.913	4.4	242	11.0	277
22.920	4.2	254	11.8	277
22.927	4.1	254	11.4	285
22.934	4.0	249	11.1	289
22.941	3.8	256	11.7	284
22.948	5.1	258	14.0	275
22.955	5.1	261	12.5	284
22.962	5.6	258	12.7	282
22.969	6.0	251	12.7	284
22.976	5.9	252	13.7	282
22.983	6.5	251	14.6	282
22.990	6.6	252	14.9	283
22.997	6.9	249	14.4	280
23.004	7.1	249	14.0	278
23.010	7.3	243	14.9	277
23.017	7.6	248	14.0	277
23.024	7.5	246	15.4	278
23.031	8.3	243	14.8	279
23.038	8.6	248	17.1	283
23.045	8.6	247	16.2	282
23.052	9.0	246	16.0	283
23.059	9.0	246	16.5	278
23.066	9.1	249	15.4	286
23.073	8.9	246	15.5	287
23.080	8.8	247	15.9	284
23.087	9.0	248	16.8	281
23.094	9.1	248	16.5	278
23.101	9.3	248	17.6	281
23.108	9.6	251	16.9	282
23.115	9.9	252	17.2	287
23.122	9.8	250	16.4	288
23.129	10.0	250	17.8	286
23.135	10.0	249	16.7	286
23.142	10.1	248	17.3	286
23.149	10.4	248	17.6	284
23.156	10.5	247	17.1	285
23.163	9.9	249	17.1	286
23.170	10.0	248	15.8	286
23.177	9.8	248	16.8	290
23.184	9.8	248	16.4	281
23.191	9.0	248	16.4	285
23.198	8.3	249	15.3	285

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
23.205	8.5	249	16.2	287
23.212	7.6	252	13.9	282
23.219	7.4	260	13.0	291
23.226	7.3	272	13.2	288
23.233	7.7	276	15.5	300
23.240	7.8	279	14.8	306
23.247	8.1	280	14.6	311
26.837	2.2	163	7.4	35
26.844	2.7	174	6.6	83
26.851	2.1	169	7.8	55
26.858	2.1	175	7.4	118
26.865	3.1	173	8.3	118
26.872	3.4	174	7.9	132
26.879	3.6	189	9.6	110
26.885	3.1	195	8.7	22
26.892	3.7	175	5.9	121
26.899	3.7	193	10.0	99
26.906	3.9	194	7.1	145
26.913	3.7	200	8.0	51
26.920	3.5	206	8.4	47
26.927	2.8	196	16.2	154
26.934	3.2	204	11.4	140
26.941	3.3	203	7.3	356
26.948	3.6	210	9.2	24
26.955	3.1	213	13.6	70
26.962	2.9	222	12.2	291
26.969	3.3	214	13.6	315
26.976	3.6	218	8.5	282
26.983	3.2	218	15.3	318
26.990	3.2	222	13.5	230
26.997	2.9	247	16.5	196
27.004	3.1	255	14.4	200
27.010	3.1	253	16.2	208
27.017	3.2	255	18.6	202
27.024	3.1	254	11.1	227
27.031	3.6	254	13.0	219
27.038	3.3	243	12.7	224
27.045	3.7	248	13.2	220
27.052	3.6	261	11.3	225
27.059	4.0	266	10.7	221
27.066	4.3	247	13.6	207
27.073	4.0	261	14.8	217
27.080	4.0	262	13.5	213
27.087	4.4	261	13.9	229
27.094	3.9	260	10.4	222
27.101	3.9	271	13.2	219
27.108	4.0	273	10.0	236
27.115	4.0	271	14.4	208
27.122	3.7	260	10.7	225
27.129	4.0	251	12.8	225
27.135	3.9	257	13.1	218
27.142	4.7	260	12.4	222
27.149	4.4	272	10.0	229
27.156	4.2	275	9.2	227
27.163	4.3	269	10.4	222
30.385	7.2	28	16.9	59
30.392	7.3	24	18.0	60
30.399	7.6	27	18.3	62

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
30.406	7.4	32	16.8	65
30.413	7.4	37	17.1	61
30.420	7.5	38	17.6	67
30.427	7.4	46	17.4	72
30.434	7.5	49	17.3	77
30.441	7.4	58	16.0	81
30.448	7.2	70	16.4	83
30.455	7.3	64	15.7	83
30.462	7.3	73	16.5	83
30.469	6.8	73	15.3	86
30.476	7.0	77	16.4	89
30.483	7.4	81	17.1	94
30.490	7.3	79	16.8	93
30.497	7.1	79	16.7	98
30.504	7.2	80	16.4	98
30.510	6.9	82	16.2	101
30.517	6.6	89	16.1	105
30.524	6.2	89	15.4	102
30.531	6.4	104	15.2	109
30.538	6.2	109	16.7	111
30.545	6.1	103	14.8	115
30.552	5.8	109	14.4	120
30.559	6.0	113	14.4	122
30.566	5.8	109	14.6	122
30.573	5.6	113	15.1	127
30.580	5.8	111	13.7	131
30.587	5.5	121	14.8	135
30.594	5.1	119	12.1	129
30.601	4.6	130	11.7	134
30.608	4.8	128	13.0	138
30.615	6.1	133	15.7	142
30.622	6.7	133	17.6	136
30.629	6.7	133	16.6	143
30.635	7.4	135	17.9	147
30.642	8.6	142	19.5	151
30.649	8.5	128	21.5	150
30.656	8.6	128	19.9	156
30.663	8.3	129	19.1	156
30.670	8.4	129	19.2	157
30.677	8.0	131	18.8	156
30.684	7.8	129	17.9	157
30.691	8.0	128	19.0	157
30.698	8.0	130	18.7	162
30.705	7.9	135	18.1	158
30.712	8.0	132	19.2	163
30.719	8.0	131	19.3	165
30.726	7.8	134	18.6	163
30.733	7.9	134	19.1	165
30.740	7.8	139	19.0	166
30.747	7.7	133	17.3	162
30.754	7.8	129	16.4	162
30.760	7.6	126	17.2	153
30.767	8.2	128	17.4	158
30.774	8.3	123	19.5	154
30.781	8.9	122	19.5	152
30.788	9.1	121	21.0	147
30.795	8.7	124	20.6	150
30.802	9.3	124	19.5	150

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
30.809	9.2	119	19.6	152
30.816	9.6	121	20.1	153
30.823	9.8	118	21.6	150
30.830	10.3	120	22.2	147
30.837	10.2	122	21.3	149
30.844	10.4	120	21.2	151
30.851	10.3	120	21.7	150
30.858	9.9	122	22.4	152
30.865	10.1	123	20.9	152
30.872	10.2	122	20.0	151
30.879	10.2	122	21.1	151
30.885	10.3	121	21.3	148
30.892	9.8	125	20.6	152
30.899	9.9	125	20.2	151
30.906	9.8	125	20.5	148
30.913	9.9	123	20.7	150
30.920	10.1	127	20.7	154
30.927	9.5	124	21.4	154
30.934	9.5	123	20.4	152
30.941	9.9	123	21.6	151
30.948	9.9	123	21.0	154
30.955	10.5	122	21.2	153
30.962	10.3	126	21.3	155
30.969	10.2	122	22.8	151
30.976	10.3	120	22.3	155
30.983	10.3	123	22.2	156
30.990	10.8	124	21.9	156
30.997	10.4	123	23.2	154
31.004	11.2	125	21.3	154
31.010	11.8	127	22.5	153
31.017	11.6	125	21.7	154
31.024	11.8	127	22.5	157
31.031	12.2	124	22.3	162
31.038	11.8	128	22.6	161
31.045	11.6	129	21.2	156

A-4 Sea Kayak Leeway Runs 113 and 116

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
18.775	10.5	182	20.9	197
18.782	10.7	184	23.1	190
18.789	10.6	182	20.8	191
18.796	10.5	178	21.4	185
18.802	10.4	175	20.0	186
18.809	10.2	174	19.3	177
18.816	9.7	175	20.3	179
18.823	10.4	170	19.2	179
18.830	10.3	171	19.0	176
18.837	10.6	172	19.7	176
18.844	10.3	166	20.7	178
18.851	10.8	162	21.4	173
18.858	11.2	161	19.6	169

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
18.865	10.7	164	19.9	173
18.872	10.6	169	18.1	172
18.879	10.8	172	18.9	174
18.886	10.4	173	20.0	175
18.893	10.1	173	18.6	181
18.900	9.8	180	18.8	188
18.907	9.3	181	17.8	191
18.914	9.3	184	17.7	193
18.921	9.3	182	15.2	193
18.927	8.4	178	15.3	196
18.934	8.8	181	15.3	195
18.941	8.6	179	13.8	186
18.948	8.3	181	14.7	185
18.955	8.6	177	14.4	188
18.962	8.3	177	15.1	192
18.969	8.1	174	14.5	189
18.976	8.0	178	15.5	189
18.983	8.2	183	14.8	192
18.990	7.9	177	15.5	194
18.997	6.1	176	14.8	192
19.004	4.3	177	14.5	191
19.011	4.4	179	14.8	194
19.018	4.3	185	14.6	191
19.025	4.1	177	14.0	188
19.032	3.6	184	14.1	190
19.039	3.3	186	13.3	197
19.046	3.9	180	15.2	204
19.052	3.8	186	15.1	200
19.059	4.0	179	15.4	203
19.066	3.8	183	14.1	209
19.073	3.7	183	14.0	196
19.080	3.9	182	13.0	206
19.087	3.7	191	14.1	216
19.094	3.6	191	13.8	209
19.101	3.3	189	13.5	209
19.108	3.3	192	12.1	205
19.115	3.5	194	12.2	209
19.122	3.7	186	14.8	208
19.129	3.6	186	13.5	207
19.136	3.3	191	13.4	199
19.143	3.7	181	12.7	203
19.150	3.7	182	11.8	207
19.157	3.2	183	13.6	197
19.164	3.6	178	13.1	204
19.171	3.8	184	12.4	193
19.177	3.6	180	13.6	204
19.184	3.8	182	15.1	204
19.191	3.5	185	13.6	203
19.198	3.4	184	13.6	205
19.205	4.9	190	13.5	201
19.212	4.9	178	12.0	191
19.219	5.0	186	13.1	190
19.226	4.9	185	13.1	190
19.233	4.2	186	13.6	189
19.240	3.3	180	13.2	181
19.247	3.5	142	14.0	191
19.254	4.3	136	9.7	186
19.261	3.6	137	13.8	178

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
19.268	4.8	146	16.3	174
19.275	5.9	133	14.2	176
19.282	5.3	147	13.8	177
19.289	4.9	149	14.2	183
19.296	4.8	146	12.9	185
19.302	4.7	158	13.3	191
19.309	4.5	157	13.7	187
19.316	4.3	153	15.3	189
19.323	3.3	164	13.2	208
19.330	3.4	166	13.0	202
19.337	3.3	146	13.8	197
19.344	2.8	157	11.2	194
19.351	3.3	155	14.4	195
19.358	3.2	166	14.0	195
19.365	4.2	156	14.5	192
19.372	4.2	162	15.3	195
19.379	4.2	168	15.9	199
19.386	4.2	173	15.2	204
19.393	4.2	178	13.5	218
19.400	3.5	180	15.7	214
19.407	3.7	159	14.9	210
19.414	3.7	158	13.8	205
19.421	4.4	152	13.1	199
19.427	4.3	152	13.6	203
19.434	3.9	153	12.9	199
19.441	3.7	158	15.0	200
19.448	4.2	155	14.5	217
19.455	3.9	170	13.7	212
19.462	3.8	172	13.8	219
19.469	3.4	204	14.0	213
19.476	3.4	205	12.1	222
19.483	3.2	199	12.2	220
19.490	3.3	180	11.4	219
19.497	3.4	156	13.1	210
19.504	3.7	174	13.4	196
19.511	3.5	191	13.4	201
19.518	3.6	180	12.7	214
19.525	3.2	184	13.2	216
19.532	3.1	183	13.4	204
19.539	3.2	203	12.7	213
19.546	3.0	197	11.9	229
19.552	2.8	204	11.3	229
19.559	2.9	218	11.3	233
19.566	3.0	218	11.7	236
19.573	3.3	202	11.5	236
19.580	3.4	209	11.8	234
19.587	3.2	206	11.0	241
19.594	2.8	216	11.4	242
19.601	2.3	213	10.5	261
19.608	3.1	189	11.2	248
19.615	3.1	201	10.8	246
19.622	3.0	196	10.9	236
19.629	3.2	191	11.4	233
19.636	3.3	185	11.0	224
19.643	3.0	182	11.5	230
19.650	3.5	191	11.7	232
19.657	3.1	186	10.9	234
19.664	3.2	180	10.7	231

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
19.671	2.7	198	11.1	227
19.677	3.2	186	11.3	232
19.684	3.1	191	12.6	235
19.691	3.6	191	12.9	235
21.775	5.7	160	20.5	151
21.782	4.7	159	19.3	155
21.789	5.2	145	19.7	148
21.796	5.5	136	21.2	140
21.802	4.5	147	18.6	143
21.809	5.1	154	20.8	145
21.816	4.7	148	19.0	148
21.823	4.9	149	20.1	149
21.830	4.9	141	20.3	142
21.837	4.9	137	19.9	137
21.844	5.1	119	18.6	135
21.851	4.9	123	19.7	133
21.858	5.2	121	21.4	124
21.865	5.2	134	20.0	132
21.872	4.8	132	19.8	133
21.879	4.7	136	20.3	127
21.886	5.6	137	21.6	134
21.893	5.4	133	21.3	128
21.900	5.3	132	21.6	128
21.907	5.0	144	20.1	133
21.914	4.8	136	20.1	135
21.921	4.7	137	20.0	134
21.927	4.6	133	20.0	131
21.934	4.9	139	21.1	133
21.941	4.9	136	20.4	139
21.948	5.2	141	20.5	137
21.955	5.8	134	22.8	135
21.962	5.7	136	21.4	141
21.969	5.9	132	23.0	136
21.976	6.9	136	23.4	128
21.983	7.7	132	24.1	133
21.990	8.0	129	24.8	127
21.997	7.2	132	22.6	130
22.004	6.5	131	23.0	127
22.011	6.7	139	23.7	134
22.018	6.8	137	23.4	140
22.025	6.5	137	22.3	137
22.032	6.8	135	21.9	143
22.039	6.8	135	21.5	137
22.046	6.4	135	23.7	134
22.052	6.0	141	23.1	137
22.059	5.7	145	22.0	128
22.066	5.9	139	20.9	135
22.073	5.5	134	22.4	135
22.080	6.1	137	23.4	130
22.087	5.5	141	22.0	134
22.094	6.1	144	23.4	141
22.101	6.1	141	23.5	140
22.108	5.8	143	22.5	135
22.115	5.6	151	22.8	140
22.122	4.9	144	22.9	136
22.129	4.9	138	21.5	138
22.136	4.4	131	20.4	136
22.143	4.6	135	21.5	141

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.150	5.0	145	22.1	137
22.157	5.1	138	21.7	134
22.164	5.6	143	21.2	137
22.171	5.7	137	23.1	138
22.177	5.4	145	21.8	135
22.184	4.2	133	19.6	137
22.191	4.2	136	19.9	132
22.198	4.0	135	19.3	134
22.205	4.2	145	21.1	136
22.212	4.1	129	19.4	129
22.219	4.1	145	19.9	134
22.226	3.5	135	19.1	134
22.233	3.2	124	18.7	139
22.240	2.9	126	17.5	127
22.247	3.1	133	17.4	129
22.254	3.0	132	18.1	132
22.261	2.9	133	17.9	132
22.268	2.7	126	15.9	141
22.275	3.3	132	16.1	137
22.282	4.0	134	18.8	130
22.289	3.6	131	20.0	133
22.296	4.4	140	21.6	129
22.302	4.2	135	21.5	133
22.309	3.5	135	21.0	138
22.316	3.9	143	22.2	139
22.323	4.2	136	22.1	138
22.330	4.3	151	22.3	137
22.337	4.2	151	21.8	140
22.344	4.7	144	22.1	144
22.351	4.3	153	23.5	141
22.358	4.7	153	22.1	140
22.365	4.8	146	22.9	143
22.372	4.4	150	21.4	140
22.379	4.6	150	21.4	140
22.386	4.5	156	22.7	143
22.393	4.6	169	22.4	146
22.400	4.4	161	21.6	151
22.407	4.8	158	21.7	149
22.414	4.3	159	22.1	148
22.421	4.7	164	23.2	152
22.427	4.4	163	21.9	152
22.434	3.9	170	21.2	154
22.441	4.3	160	20.9	154
22.448	4.5	157	21.8	154
22.455	4.1	166	21.9	155
22.462	4.3	170	21.2	154
22.469	4.1	168	20.9	159
22.476	3.4	168	19.8	158
22.483	2.4	181	20.0	160
22.490	2.6	184	18.3	162
22.497	3.3	182	17.1	164
22.504	3.2	179	17.7	166
22.511	3.1	160	17.3	162
22.518	3.4	187	18.0	167
22.525	3.2	171	18.5	163
22.532	2.7	182	15.6	167
22.539	3.0	180	15.4	178
22.546	2.9	185	16.0	173

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.552	2.6	184	15.9	174
22.559	2.9	183	15.8	182
22.566	3.1	170	16.2	169
22.573	2.6	181	14.8	170
22.580	2.2	193	16.0	181
22.587	2.5	187	15.8	169
22.594	2.2	188	15.6	165
22.601	2.3	189	16.2	169
22.608	2.7	188	14.8	169
22.615	2.6	174	13.9	170
22.622	2.4	179	14.1	175
22.629	2.3	192	13.8	173
22.636	2.2	211	13.4	173
22.643	2.1	197	14.3	172
22.650	2.2	179	13.8	177
22.657	2.4	168	14.2	163
22.664	2.0	196	13.8	168
22.671	2.8	174	13.6	174
22.677	2.6	193	13.1	177
22.684	2.0	219	13.0	180
22.691	2.4	202	12.9	184
22.698	2.1	187	13.1	186
22.705	2.2	205	13.2	180
22.712	2.0	196	12.3	183
22.719	2.9	182	12.9	189
22.726	2.7	209	12.6	190
22.733	2.0	215	13.1	194
22.740	2.8	209	12.2	206
22.747	2.8	199	12.9	199
22.754	2.1	219	12.0	208
22.761	2.8	220	14.0	202
22.768	2.7	229	13.0	217
22.775	2.5	232	14.0	216
22.782	2.6	225	13.1	217
22.789	2.7	224	13.6	221
22.796	3.2	236	13.8	229
22.802	3.1	229	14.0	226
22.809	2.8	235	15.3	236
22.816	2.3	241	15.8	232
22.823	2.6	256	15.5	235
22.830	3.0	242	16.8	230
22.837	3.8	240	17.7	239
22.844	3.5	236	18.3	244
22.851	3.7	249	20.5	244
22.858	3.3	243	20.6	240
22.865	3.7	250	17.8	255
22.872	3.6	245	18.2	267
22.879	3.5	250	18.3	265
22.886	3.4	252	18.7	272
22.893	3.4	242	18.2	263
22.900	3.8	249	17.4	263
22.907	4.3	245	19.1	259
22.914	4.4	242	20.8	259
22.921	4.2	254	20.1	262
22.927	4.1	254	21.5	270
22.934	4.0	249	22.1	265
22.941	3.8	256	22.5	269
22.948	5.1	258	26.4	269

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.955	5.1	261	26.0	269
22.962	5.6	258	24.6	264
22.969	6.0	251	23.7	259
22.976	5.9	252	25.7	258
22.983	6.5	251	24.0	267
22.990	6.6	252	25.5	263
22.997	6.9	249	25.7	266
23.004	7.1	249	24.6	259
23.011	7.3	243	24.3	263
23.018	7.6	248	25.4	258
23.025	7.5	246	24.8	258
23.032	8.3	243	23.4	261
23.039	8.6	248	24.7	260
23.046	8.6	247	23.9	260
23.052	9.0	246	25.0	260
23.059	9.0	246	25.6	260
23.066	9.1	249	26.1	261
23.073	8.9	246	24.3	264
23.080	8.8	247	25.5	268
23.087	9.0	248	24.5	267
23.094	9.1	248	24.7	264
23.101	9.3	248	23.6	261
23.108	9.6	251	24.5	265
23.115	9.9	252	23.1	267
23.122	9.8	250	22.8	269
23.129	10.0	250	24.5	265
23.136	10.0	249	24.4	262
23.143	10.1	248	22.8	271
23.150	10.4	248	23.4	269
23.157	10.5	247	22.3	260
23.164	9.9	249	23.0	266
23.171	10.0	248	22.3	267
23.177	9.8	248	22.7	262
23.184	9.8	248	21.8	266
23.191	9.0	248	23.5	272
23.198	8.3	249	21.5	258
23.205	8.5	249	23.5	263
23.212	7.6	252	21.2	267
23.219	7.4	260	22.1	263
23.226	7.3	272	22.1	271
23.233	7.7	276	23.7	289
23.240	7.8	279	22.6	288

A-5 Windsurfer Leeway Runs 115 and 118

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
18.997	6.1	176	14.4	142
19.004	4.3	177	17.0	162
19.010	4.4	179	12.5	150
19.017	4.3	185	13.7	154
19.024	4.1	177	12.5	155
19.031	3.6	184	13.4	160

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
19.038	3.3	186	14.8	155
19.045	3.9	180	13.7	173
19.052	3.8	186	15.0	170
19.059	4.0	179	11.2	165
19.066	3.8	183	14.6	158
19.073	3.7	183	12.8	156
19.080	3.9	182	11.9	156
19.087	3.7	191	15.3	156
19.094	3.6	191	13.4	162
19.101	3.3	189	12.1	178
19.108	3.3	192	13.8	155
19.115	3.5	194	12.1	155
19.122	3.7	186	13.2	163
19.129	3.6	186	10.8	183
19.135	3.3	191	11.2	160
19.142	3.7	181	10.4	138
19.149	3.7	182	12.0	152
19.156	3.2	183	11.5	153
19.163	3.6	178	11.3	158
19.170	3.8	184	11.5	155
19.177	3.6	180	10.5	168
19.184	3.8	182	11.8	158
19.191	3.5	185	15.0	159
19.198	3.4	184	12.2	164
19.205	4.9	190	13.3	153
19.212	4.9	178	15.9	159
19.219	5.0	186	14.9	144
19.226	4.9	185	13.8	146
19.233	4.2	186	13.1	167
19.240	3.3	180	12.6	147
19.247	3.5	142	9.9	149
19.254	4.3	136	9.3	149
19.260	3.6	137	13.5	139
19.267	4.8	146	16.6	128
19.274	5.9	133	14.6	131
19.281	5.3	147	17.4	147
19.288	4.9	149	13.6	147
19.295	4.8	146	13.4	156
19.302	4.7	158	13.0	145
19.309	4.5	157	15.0	150
19.316	4.3	153	14.7	152
19.323	3.3	164	13.1	150
19.330	3.4	166	11.6	157
19.337	3.3	146	8.8	151
19.344	2.8	157	11.1	159
19.351	3.3	155	10.2	158
19.358	3.2	166	12.8	153
19.365	4.2	156	12.5	140
19.372	4.2	162	13.1	160
19.379	4.2	168	16.4	157
19.385	4.2	173	15.4	157
19.392	4.2	178	13.2	178
19.399	3.5	180	11.7	188
19.406	3.7	159	11.3	178
19.413	3.7	158	9.7	166
19.420	4.4	152	13.0	160
19.427	4.3	152	13.0	157
19.434	3.9	153	12.4	157

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
19.441	3.7	158	11.3	168
19.448	4.2	155	10.7	169
19.455	3.9	170	12.1	175
19.462	3.8	172	13.3	163
19.469	3.4	204	10.7	182
19.476	3.4	205	10.4	198
19.483	3.2	199	10.2	175
19.490	3.3	180	8.5	185
19.497	3.4	156	11.9	180
19.504	3.7	174	8.5	197
19.510	3.5	191	10.0	184
19.517	3.6	180	8.8	173
19.524	3.2	184	11.9	169
19.531	3.1	183	10.4	182
19.538	3.2	203	8.7	199
19.545	3.0	197	6.8	214
19.552	2.8	204	8.0	206
19.559	2.9	218	7.3	216
19.566	3.0	218	7.9	230
19.573	3.3	202	9.8	229
19.580	3.4	209	10.1	216
19.587	3.2	206	12.1	220
19.594	2.8	216	11.1	228
19.601	2.3	213	8.0	224
19.608	3.1	189	8.7	216
19.615	3.1	201	9.1	217
19.622	3.0	196	11.8	215
19.629	3.2	191	11.8	205
19.635	3.3	185	9.5	201
19.642	3.0	182	11.3	194
19.649	3.5	191	8.9	209
19.656	3.1	186	7.7	205
19.663	3.2	180	7.9	201
19.670	2.7	198	10.9	208
19.677	3.2	186	10.4	194
19.684	3.1	191	9.3	206
19.691	3.6	191	11.7	202
21.774	5.7	160	17.8	152
21.781	4.7	159	15.1	145
21.788	5.2	145	17.9	137
21.795	5.5	136	16.2	132
21.802	4.5	147	13.4	130
21.809	5.1	154	13.9	148
21.816	4.7	148	15.5	141
21.823	4.9	149	11.6	158
21.830	4.9	141	14.2	129
21.837	4.9	137	16.2	128
21.844	5.1	119	14.6	124
21.851	4.9	123	15.5	124
21.858	5.2	121	17.9	120
21.865	5.2	134	16.6	122
21.872	4.8	132	14.5	128
21.879	4.7	136	13.7	124
21.885	5.6	137	19.9	131
21.892	5.4	133	19.1	134
21.899	5.3	132	18.9	133
21.906	5.0	144	16.1	126
21.913	4.8	136	15.9	136

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
21.920	4.7	137	13.5	129
21.927	4.6	133	15.0	136
21.934	4.9	139	17.8	125
21.941	4.9	136	18.4	139
21.948	5.2	141	17.6	132
21.955	5.8	134	19.9	136
21.962	5.7	136	16.7	125
21.969	5.9	132	20.5	131
21.976	6.9	136	22.8	134
21.983	7.7	132	25.6	125
21.990	8.0	129	24.5	123
21.997	7.2	132	22.9	127
22.004	6.5	131	22.7	136
22.010	6.7	139	23.5	136
22.017	6.8	137	22.3	131
22.024	6.5	137	17.6	132
22.031	6.8	135	20.1	131
22.038	6.8	135	22.4	139
22.045	6.4	135	22.0	128
22.052	6.0	141	20.5	132
22.059	5.7	145	20.3	140
22.066	5.9	139	20.6	137
22.073	5.5	134	18.6	126
22.080	6.1	137	18.6	127
22.087	5.5	141	21.5	132
22.094	6.1	144	21.3	132
22.101	6.1	141	20.7	142
22.108	5.8	143	19.3	145
22.115	5.6	151	18.8	132
22.122	4.9	144	18.8	132
22.129	4.9	138	15.8	136
22.135	4.4	131	16.0	134
22.142	4.6	135	18.0	144
22.149	5.0	145	17.5	134
22.156	5.1	138	19.0	145
22.163	5.6	143	17.8	139
22.170	5.7	137	19.6	138
22.177	5.4	145	17.9	125
22.184	4.2	133	14.4	128
22.191	4.2	136	17.1	140
22.198	4.0	135	15.8	138
22.205	4.2	145	14.2	135
22.212	4.1	129	16.1	133
22.219	4.1	145	17.3	136
22.226	3.5	135	15.2	139
22.233	3.2	124	13.2	135
22.240	2.9	126	12.3	129
22.247	3.1	133	13.3	133
22.254	3.0	132	13.1	137
22.260	2.9	133	11.0	140
22.267	2.7	126	11.4	133
22.274	3.3	132	12.3	125
22.281	4.0	134	14.6	128
22.288	3.6	131	15.3	132
22.295	4.4	140	16.7	143
22.302	4.2	135	16.7	151
22.309	3.5	135	16.0	136
22.316	3.9	143	14.6	145

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.323	4.2	136	16.1	138
22.330	4.3	151	16.6	146
22.337	4.2	151	16.8	151
22.344	4.7	144	17.6	156
22.351	4.3	153	16.6	158
22.358	4.7	153	18.7	132
22.365	4.8	146	15.2	157
22.372	4.4	150	18.5	151
22.379	4.6	150	18.7	156
22.385	4.5	156	16.4	154
22.392	4.6	169	17.9	163
22.399	4.4	161	17.8	146
22.406	4.8	158	17.5	163
22.413	4.3	159	15.6	162
22.420	4.7	164	17.4	152
22.427	4.4	163	16.0	160
22.434	3.9	170	15.1	156
22.441	4.3	160	16.0	159
22.448	4.5	157	16.6	152
22.455	4.1	166	14.1	165
22.462	4.3	170	18.1	155
22.469	4.1	168	12.9	168
22.476	3.4	168	14.7	175
22.483	2.4	181	11.8	169
22.490	2.6	184	10.4	161
22.497	3.3	182	15.2	165
22.504	3.2	179	13.0	171
22.510	3.1	160	12.8	163
22.517	3.4	187	14.0	165
22.524	3.2	171	12.5	172
22.531	2.7	182	12.8	174
22.538	3.0	180	11.2	164
22.545	2.9	185	12.8	176
22.552	2.6	184	13.7	175
22.559	2.9	183	12.5	171
22.566	3.1	170	15.3	174
22.573	2.6	181	14.1	174
22.580	2.2	193	12.9	164
22.587	2.5	187	13.0	171
22.594	2.2	188	13.2	165
22.601	2.3	189	11.8	166
22.608	2.7	188	10.9	180
22.615	2.6	174	9.3	176
22.622	2.4	179	9.1	192
22.629	2.3	192	10.2	169
22.635	2.2	211	12.1	186
22.642	2.1	197	12.4	179
22.649	2.2	179	12.0	184
22.656	2.4	168	13.6	164
22.663	2.0	196	8.9	178
22.670	2.8	174	13.3	184
22.677	2.6	193	10.1	205
22.684	2.0	219	9.3	192
22.691	2.4	202	7.9	183
22.698	2.1	187	10.7	172
22.705	2.2	205	11.6	170
22.712	2.0	196	10.9	177
22.719	2.9	182	11.6	201

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
22.726	2.7	209	13.9	202
22.733	2.0	215	8.9	204
22.740	2.8	209	10.8	213
22.747	2.8	199	13.3	201
22.754	2.1	219	12.6	213
22.760	2.8	220	11.8	227
22.767	2.7	229	15.2	234
22.774	2.5	232	11.5	238
22.781	2.6	225	13.4	227
22.788	2.7	224	12.0	225
22.795	3.2	236	13.8	238
22.802	3.1	229	14.6	236
22.809	2.8	235	14.0	229
22.816	2.3	241	12.5	237
22.823	2.6	256	14.4	230
22.830	3.0	242	15.9	230
22.837	3.8	240	18.7	236
22.844	3.5	236	17.8	243
22.851	3.7	249	19.0	237
22.858	3.3	243	17.6	238
22.865	3.7	250	16.0	245
22.872	3.6	245	18.3	241
22.879	3.5	250	15.5	243
22.885	3.4	252	16.5	238
22.892	3.4	242	16.7	243
22.899	3.8	249	20.3	245
22.906	4.3	245	18.7	242
22.913	4.4	242	21.1	249
22.920	4.2	254	16.4	248
22.927	4.1	254	16.7	246
22.934	4.0	249	17.8	254
22.941	3.8	256	17.9	242
22.948	5.1	258	19.2	254
22.955	5.1	261	18.9	252
22.962	5.6	258	21.2	250
22.969	6.0	251	23.5	256
22.976	5.9	252	24.2	248
22.983	6.5	251	25.7	246
22.990	6.6	252	23.4	251
22.997	6.9	249	24.8	244
23.004	7.1	249	24.4	243
23.010	7.3	243	22.1	235
23.017	7.6	248	23.0	240
23.024	7.5	246	22.1	232
23.031	8.3	243	24.4	225
23.038	8.6	248	24.0	231
23.045	8.6	247	26.5	233
23.052	9.0	246	26.8	234
23.059	9.0	246	26.4	228
23.066	9.1	249	25.8	235
23.073	8.9	246	26.6	234
23.080	8.8	247	26.4	226
23.087	9.0	248	24.8	231
23.094	9.1	248	24.5	226
23.101	9.3	248	28.1	232
23.108	9.6	251	25.9	233
23.115	9.9	252	27.2	230
23.122	9.8	250	24.6	239

Decimal Days	Wind Speed At 10m (m/s)	Wind Direction (° True)	Target Speed (cm/s)	Target Direction (° True)
23.129	10.0	250	28.9	236
23.135	10.0	249	27.4	230
23.142	10.1	248	26.8	237
23.149	10.4	248	26.0	234
23.156	10.5	247	28.5	226
23.163	9.9	249	27.1	229
23.170	10.0	248	28.0	227
23.177	9.8	248	25.7	234
23.184	9.8	248	25.0	227
23.191	9.0	248	23.0	243
23.198	8.3	249	24.4	241
23.205	8.5	249	20.5	239
23.212	7.6	252	20.3	251
23.219	7.4	260	22.0	254
23.226	7.3	272	24.0	270
23.233	7.7	276	24.4	281
23.240	7.8	279	28.6	283